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MODIFICATION OF THE INNATE BEHAVIOR OF COCKROACHES [1]

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Four figures

Graber's [2] experiments proved long ago that cockroaches, *Periplaneta orientalis* L, avoid the light and seek the dark. After having verified Graber's observations, I sought to change the direction of movement by teaching them, by means of the punishment method [3] to seek light and avoid darkness.

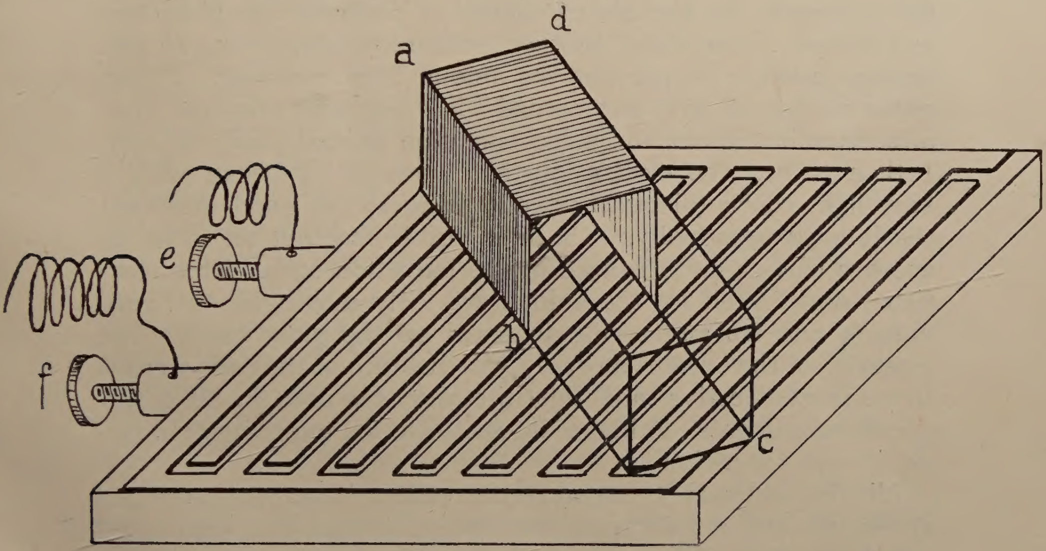

Figure 1. Apparatus for study of the modifiability of reaction to light in the cockroach. a c, glass-box; d b, covered part of box; e and f, electrodes.

The apparatus used in these experiments is shown in Figure 1.

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[1] The writer begs to acknowledge his indebtedness to Mr. Przibram, Director of the Institute for Experimental Biology in Vienna, for many helpful suggestions and criticisms.

[2] Graber, V. Grundlinien zur Erforschung des Helligskeits- und Farbensinnes des Tiere. Prag. 1884, S. 147–157.

[3] Yerkes, R. M. The dancing mouse. New York. 1907, pp. 98–99.

The base of the apparatus is formed of 29 insulated copper plates, each 0.5 cm. wide. The distance between plates is 0.1 cm. The unpaired plates are connected with a long plate on the one side of the base and the paired plates with *a similar* plate on the other side. The two long plates are connected with an induction apparatus and this, in its turn with an accumulator of 2 volts. By this manner of setting up the current, all the non-paired plates form one electrode and all the paired ones a second electrode. Above the base is a bottomless glass box, (Fig. 1 ac) 19 cm. long, 2.7 cm. wide and 8.5 cm. high. Two-fifths of this box is entirely covered with black paper (Fig. 1 db).

In order to determine at first to what degree cockroaches are influenced by the electric shock, I removed the glass box and placed in its stead another bottomless glass box, 16 cm. square, in order to prevent the animal from escaping. I then put a cockroach into this second glass box and observed that after running about for some time the animal came to rest. I then turned the electric current upon it. I began with a very light shock (distance of coils being 19 cm.) and increased the intensity gradually. The first visible reaction set in at an average of 14.5 cm. distance of the induction coils. This reaction showed itself by the animal suddenly moving about, running to and fro and trying to crawl up the glass walls. The intensity of the current at 12–13 cm. distance of the coils seemed to be most effective, and this intensity was used in all subsequent experiments. A higher intensity caused temporary paralysis, if used for a time.

All the animals I experimented upon were male larvae,[4] about one and a half years old, whose parents had been bred and kept in the Vienna Biological Institute.

During the definite experiments, and at the end of each series of experiments, the floor of the apparatus and the walls of the glass box were thoroughly cleansed with cotton wool moistened with alcohol in order to deodorize the apparatus.

After having replaced the covered glass box, Fig. 1, on the base, I started the definite experiments now to be described. A cockroach was placed in the lighter part of the box; it immediately turned towards the darker part, which it entered. Thereupon I turned the current upon it. The animal, on receiving the electric shock, ran wildly about, tried to crawl up the walls, and then ran back to the light part. As soon as it had retreated to the lighter region, I switched off the circuit. After a short time, the cockroach again entered the darkened part and received another shock. When this procedure had been repeated a variable number of times, according to individual differences, the animal running in the direction from light to dark, on attaining the boundary line between the light and the dark, would suddenly stop, move its head and thorax in all directions and begin rapidly working with its antennae. After a time it usually turned back to the light. This behavior is, I think, the first stage in the overcoming of phototropism by training; untrained cockroaches do not behave in this manner. After a short time the animal would again return to the darkness, and again receive a shock. Its behavior now completely changed, for it no longer ran about in the dark region, but at once retreated towards the light. Having attained the boundary line between light and darkness, it turned towards the light. The number of turnings back from the boundary line between darkness and light into the light without receiving a shock increased with training. I considered the training complete when the animal, being in the light, turned back to the light ten times on arriving at the boundary line between light and darkness, without receiving a shock. All of the ten cockroaches used in my experiments succeeded in doing this.

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[4] Mature animals differ externally from old larvae only by the presence of the pair of rudimentary wings.

During the experiments, when experience of the situation had already been gained, it repeatedly happened that an animal coming from the light to the boundary line between light and darkness, remained still of its own accord, with its head pointed towards the darkness. When I excited the animal to move by stroking its back (*dorsum*) by means of a strip of paper, it struggled against going into the darkness and turned towards the light in order to escape the irritating strip of paper. Table I shows the results of the experiments.

With the exception of Nos. 3 and 5, the cockroaches were tested at the same time of day, two o'clock in the afternoon, without intermission until they finally made the required number of turnings back. The time necessary for training was on the average from three-quarters to one hour. The training of Nos. 3 and 5 could not be finished on the same day because of the great fatigue from which they suffered. As the table shows, there are very great differences in their modes of learning

TABLE I

Reactions of Cockroaches to Electric Shock when Moving Toward a Dark Box

Number of animal	Number of shocks	Number of turnings back
1	5	1
	12	5
	15	4
	16	5
	17	5
	18	1
	20	1
	21	5
	22	1
	25	3
	27	2
	31	3
	32	2
	33	1
	36	2
	37	10
2	6	1
	7	1
	23	1
	24	2
	28	10
3	11	1
	13	2
	21	1
	22	1
	41	1
	42	1
	52	1
	58	6
	64	5
	65	3
	67	2
	68	2
	69	1
	70	1
	71	1
	87	1
	(pause of 2 days)	
	106	3
	107	4
	112	1
	113	1
	114	7
	115	4
	116	10
4	7	2
	8	1
	9	1
	10	3
	11	1
	12	4
	13	8
	14	1
	15	7
	16	10
5	30	3
	32	1
	37	2
	38	2
	40	2
	43	4
	44	2
	45	6
	46	3
	61	2
	70	1
	(pause of 1 day)	
	87	1
	88	6
	94	5
	95	6
	96	10
6	12	1
	19	2
	23	2
	27	1
	35	3
	37	1
	41	8
	42	5
	43	1
	44	10
	19	3
	20	1

TABLE I—*Continued*

Number of animal	Number of shocks	Number of turnings back	Number of animal	Number of shocks	Number of turnings back
7	22	1		29	8
	25	2		37	10
	27	1			
	31	6	10	10	2
	32	10		12	1
				23	1
				37	1
8	6	4		39	3
	7	2		49	4
	12	1		50	2
	13	4		55	5
	14	4		56	1
	15	6		58	1
	17	8		63	1
	21	4		68	5
	22	2		82	1
	23	10		93	2
				94	1
				95	9
9	8	1		100	3
	12	3		105	1
	14	6		109	1
	22	6		112	6
	23	2		114	1
	28	4		118	10

While 16 shocks were sufficient for No. 4, No. 10 performed the ten obligatory turnings back only after having received 118 shocks. It may therefore be assumed from the different manners of learning that there were three types of cockroaches.

Let us mark the curves of learning based upon the results gained with the ten cockroaches. In all the curves, abscissas represent the number of shocks; and ordinates the number of the turnings back without receiving a new shock. Figure 2 shows the curves of Nos. 2, 4, 6, 7 and 8; Figure 3, those of Nos. 1 and 9; Figure 4, those of Nos. 3, 5 and 10.

The curves of the first series (Fig. 2) are similar in character, since they ascend successively till the crest is attained. The number of shocks necessary for producing the definite result is rather small. These data, however, prove that after the first experience of the shock, the animals made continuous progress. Thus the curves show no important or prolonged failure.

Fig. 4 represents the curve of the third series. This curve is much longer and shows that the animals learn only after having received many shocks. Perfection was gained only after a long time, but the fact that the curves Nos. 3 and 5 show two crests is particularly interesting. The one is a definite one, the other takes place about the middle of the course of the curves. The curve for No. 10 presents three crests. While the interest of the crests consists in their showing the progress of the learning, the space between the crests may be considered as the consequence of fatigue. I noticed external signs of fatigue, in all the cockroaches referred to, after the first crest had been attained. The animal remained motionless on the same spot or when excited to movement shot blindly along the walls, failing to stop on the boundary line between light and darkness. In the same way, the movements of the thorax and the antennae, previously described, ceased when the animal had arrived at the boundary line. The effect of the electric shocks upon the animal seemed to be lessened. As soon as the animals had rested, they were able to attain the second crest and the experiments were completed.

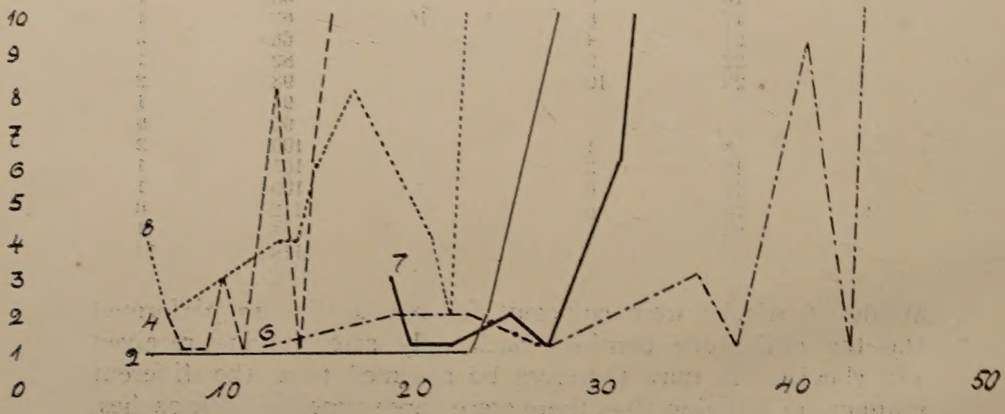

Figure 2. Representation of the reactions of cockroaches Nos. 2, 4, 6, 7, and 8. Number of turnings from dark box indicated on axis of ordinates. Number of electric shocks indicated on axis of abscissas.

The tests of No. 10 were achieved in the same trial, those of No. 3 after the elapse of one day, and those of No. 5 after two days. Thus the two elements of these curves, crests and failures, refer to two factors concerned in the process of learning: *practice* and *fatigue.*

The curves of the second series (Fig. 3) resemble those just described in that they also show two crests. The difference consists in the small number of shocks necessary to obtain definite results of learning. This circumstance, however, brings it near to the curves of the first series. Thus the curves of the second series take an intermediate position between the two others.

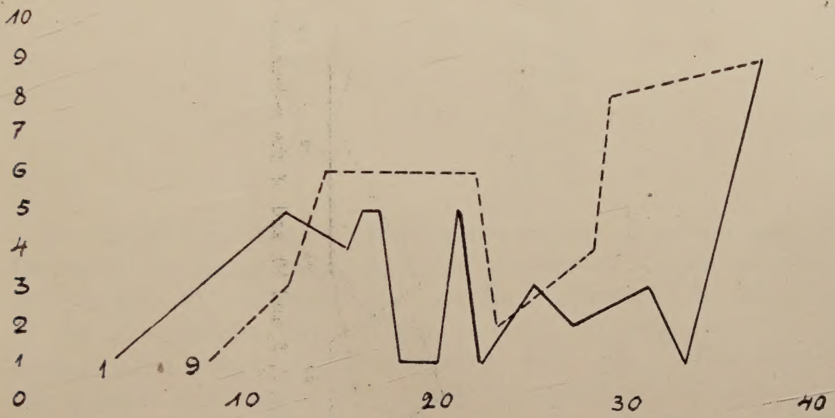

FIGURE 3. Representation of the reactions of cockroaches Nos. 1 and 9.

The results of an analysis of the curves enables us to separate the cockroaches tested with respect to their ability in learning, into three groups as shown in the following table.

	Characteristics of the curve	*Characteristic features of the cockroaches in learning*
1	Short One crest	Rapid progress with practice Slow fatigue
2	Short Two crests	Rapid progress with practice Rapid fatigue
3	Very long Two crests	Slow progress with practice Rapid fatigue

The analysis of the curves and the possibility of isolating two factors, *practice* and *fatigue*, permit us to assert that the learning-curves of cockroaches may be considered a special case of Kraepelin's "Arbeitscurve." [5]

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[5] Kraepelin. Die Arbeitscurve. Phil. Studien, 1902, Bd. 19. S. 459–507.

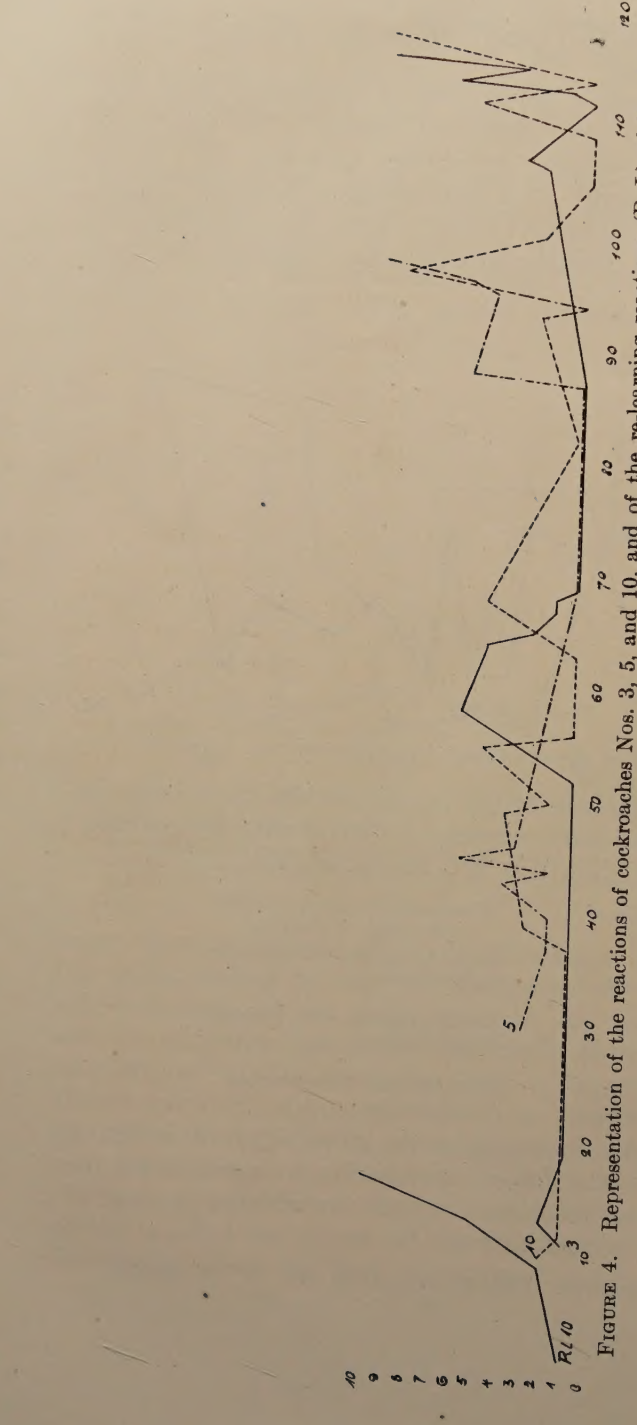

FIGURE 4. Representation of the reactions of cockroaches Nos. 3, 5, and 10, and of the re-learning reactions (R L) of No. 10.

Marked individual differences were noted with respect to the time during which the cockroaches retained their newly acquired habit.

The data given below were gathered by measuring the time elapsing between the last effective shock given and the animal's retreat into the dark part of the glass box.

TABLE II

No. of animal	Time of permanent avoiding of the dark
3	3′ 53″
9	10′ 57″
4	11′ 20″
8	11′ 48″
5	13′ 3″
2	14′ 24″
7	18′ 32″
10	25′ 15″
6	55′ 0″

No relation is evident between the degree of permanency of the newly acquired habit and the number of shocks necessary to establish it. Though the training influences the behavior of the cockroaches only for a short time, the memory of it lies latent, as is proved by the rapidity with which they relearn. An animal once trained after a few days performs the obligatory number of turnings-back after only a few shocks have been applied. The following table shows the results of relearning.

TABLE III

No. of animal	Number of shocks necessary for learning	Number of days between learning and relearning	Number of shocks necessary for relearning
10	118	1	17
9	37	2	12
8	23	3	4
4	16	6	5
1	37	9	7

The curves of relearning resemble those of the first series. They indicate rapid progress without noteworthy fatigue. As an example of the curve of relearning, I give that for No. 10, Fig. 4, R L, 10.

Before concluding my description of the experiments, I must mention that it was possible to establish the habit in an animal whose antennae had previously been removed. A hundred and twenty-six shocks were required before the animal performed the obligatory ten reversals. The learning-curve is the same as those of the third series in normal animals.

Felix Plateau [6] has recently stated, as a general conclusion drawn from his experiments with bumblebees, that "chez Bourdous et vrais-semblablement chez les autres insectes la mémoire des faits n'existe pas" (p. 159). The results of my experiments do not support this statement.

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[6] Plateau, F. Les insectes ont-ils la mémoire des faits? L'année psychologique 1909, t. 15. pp. 148–159.

THE REACTIONS OF THE FLAGELLATE *PERANEMA*

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One figure

Peranema is a colorless, cigar shaped flagellate scarcely 0.05 mm. long and but little more than 0.01 mm. in diameter. A prominent contractile vacuole is found near the anterior end from which projects a heavy flagellum nearly as long as the body, Fig. 1. It is a hardy, sluggish creature, usually found in abundance in cultures rich in decaying organic matter. I have kept specimens in excellent condition for three weeks on a slide under a cover glass sealed air-tight with vaseline. These flagellates ordinarily move in contact with solid objects or on the surface film, but sometimes they swim through the water very much like Euglena. I shall refer to the former method of locomotion as crawling. The rate of motion by either method is relatively slow, the crawling rate being only 1.3–2.6 mm. per minute and the swimming rate but very little more. Owing to this very moderate rate of locomotion it is a simple matter to follow under high magnification every movement the animal makes.

In crawling, Peranema is frequently seen to continue for considerable distances in a fairly straight line. It does not rotate as it does in swimming but proceeds with a given surface continuously in contact with the substratum to which it adheres with considerable tenacity, probably by means of secreted mucus. The flagellum extends straight forward and is rigid and motionless except for about one-sixth of the whole at the tip, which is bent at right angle so as to form a sort of hook, Fig. 1. This bent part of the flagellum vibrates rapidly, striking backward and forward in such a way that the free end describes a narrow ellipse. Thus the creature is literally drawn slowly and steadily along. This is the method of locomotion that is ordinarily seen but if the animals are strongly stimulated, as by the addition of a little iodin, marked wave-like contractions are seen to pass over the body from the posterior to the anterior end. That this wave-like contraction is at least at times functional in locomotion is shown by the fact that specimens with the flagellum removed, an operation which was repeatedly performed with a fine glass rod, are still capable of progressing, although much more slowly than before the operation. The activity of the flagellum is, however, alone sufficient to produce locomotion, for specimens are frequently seen moving quite actively and accurately in the direction of the flagellum when the body is bent at right angles to it, so that contractions in the body could not possibly function and still admit of movement in the direction of the flagellum. When iodin is added it not only induces marked contractions in the body but also much more vigorous action of the flagellum. Not only do the rate and the extent of vibration increase but a larger portion becomes active. Under such conditions the portion of the flagellum which vibrates increases from about one-sixth to more than one-half, the angle in it being much nearer the body. The combined effect of the increased activity in the flagellum and the contractions in the body causes the rate of locomotion to become almost double that ordinarily observed in crawling specimens.

If the iodin solution is strong enough the crawling specimens leave the substratum and swim freely through the water. I have never seen this method of locomotion under ordinary conditions; it must be very rare in nature. In swimming, the entire flagellum is active, having a motion somewhat like that of a snake except that it is not restricted to one plane but rotates continuously on its long axis so that it appears much like a cork-screw in motion. The body also rotates continuously when the animal swims, usually counter clockwise, like most of the free-swimming unicellular organisms, but the rotation of the flagellum is independent of this; it may often be seen when the body is stationary. As a matter of fact it is the rotation of the flagellum that causes the rotation of the body.

Reactions to Contact Stimuli.—The study of the reactions of Peranema was confined almost entirely to crawling specimens. As these animals move about they come in contact with objects, the tip of the flagellum usually striking the object first. Often when this happens there is no response. This is especially true when the object is small or when it consists of a mass of loosely compact granules or fibers, or when the flagellum strikes one side of the object. Under such conditions these creatures usually slide by or through the obstruction, their course being altered only in so far as the mechanical resistance requires. Ordinarily, however, there is a definite response when the flagellum touches an object. The organism stops, the body bends sharply always toward the larger lip, throwing the anterior end with the flagellum, usually more or less curved and inactive, to one side

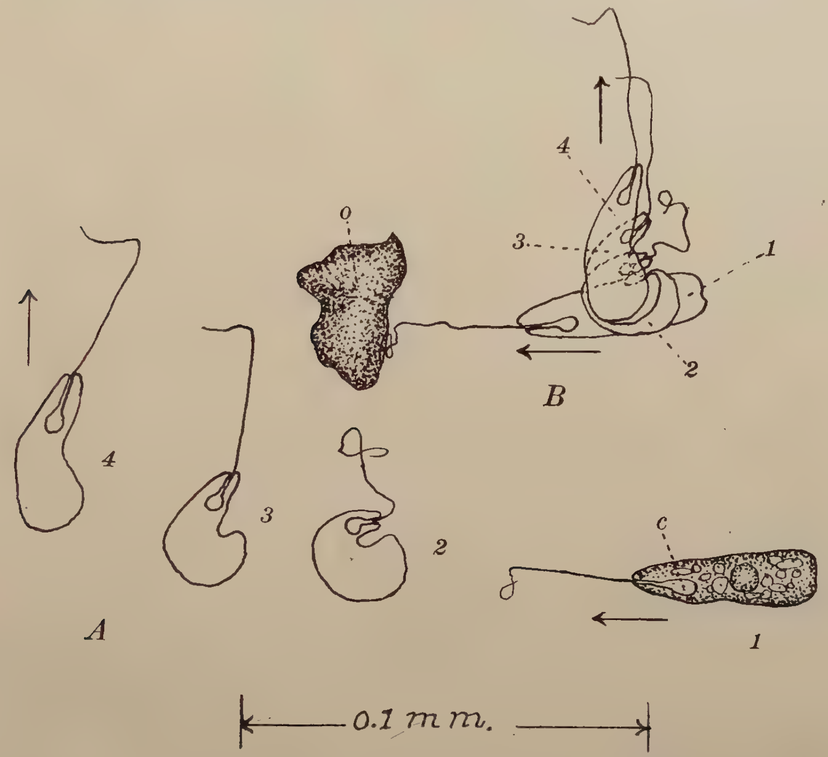

Figure 1. Camera drawings of specimens of Peranema representing the reaction to contact or chemical stimulation. A, Outline of four individuals selected from many suddenly killed in Worcester's fluid in different stages of the response. B, Outline of the same individuals superimposed to represent the relative positions of a specimen in different stages of the response; 0, solid object; 1, specimen crawling in the direction of the arrow, only the bent tip of the flagellum is active; c, contractile vacuole; 2, position taken immediately after stimulation; the flagellum is inactive, the turning of the anterior end being due to contraction on one side of the body; 3 and 4, later positions assumed, the body gradually straightens and the tip of the flagellum again becomes active. Note that the response results in a change in the direction of motion of approximately ninety degrees.

through an angle of nearly 180 degrees, Fig. 1. Then the body gradually straightens again, the anterior end turning back somewhat toward its former position, the flagellum straightens, the tip becomes active and the creature proceeds on its new course, having changed its direction of locomotion approximately 90 degrees. In this way objects are avoided which frequently have been only slightly touched by the very tip of the flagellum. This bending reaction is not dependent upon the activity of the flagellum as maintained by Verworn (Allgemeine Physiologie, 1909, p. 451). It is entirely due to contraction of one side of the body. Moreover, I was unable to obtain any evidence indicating that the direction of motion in crawling specimens is changed in any other way. Neither the beating of the flagellum nor any thing connected with the wave-like contractions of the body functions in changing the course of this animal.

The fact that Peranema responds when only the tip of the flagellum is touched indicates that this structure is sensitive to contact. It does not, however, prove that it is, for it may be that the response is due to change in pressure on the anterior end of the body owing to the contact of the flagellum or to mechanical waves transmitted through it to the body. However this may be, the animal responds precisely the same when the body is touched with a glass rod, as was repeatedly done. Moreover, this response bears no relation to the location of the stimulus on the body; it is precisely the same no matter whether the posterior or the anterior end is touched, or any other point on the surface. There is no indication whatever of a differential response to localised stimulation. Peranema differs in this respect from most of the other unicellular forms that have been tested. When Lacrymaria or Stentor e. g., is stimulated on the posterior end it ordinarily does not respond the same as when it is stimulated on the anterior end. Thus the character of the response in these creatures depends in some measure upon the location of the stimulus, while in Peranema this is not true. But in this animal there may be local response to local stimulation. One often sees contraction of the tissue in the immediate region to which the stimulus is applied, and these contractions may spread over the body in wave-like form. Whether or not the direction and the character of the wave is dependent upon the location of the stimulus I am unable to say. At any rate the direction of motion is not changed by reactions of this nature, although the rate may be.

Thus we see that the reactions of Peranema which regulate the direction of motion are in the nature of trial movements. There is no indication of orientation and procedure directly toward or from objects or solutions, nothing in the nature of a tropism as defined by Loeb. When the animal is stimulated, no matter how or where, it either moves more rapidly or stops, bends toward a given side and takes another course. If this relieves the stimulus it continues, if not it repeats the reaction until the stimulus does not again occur.

In this connection it is interesting to consider the reactions of specimens entangled in debris. The first response seen after a specimen gets into a fibrous mass which affords some obstruction is an increase in the activity of the flagellum. The tip does not only strike back and forth more vigorously but a larger portion becomes active. If this does not result in freeing the creature it responds by bending the body sharply, i.e., with the bending reaction, and starts in a different direction, after which, if still held fast, it may again lash the flagellum furiously and then again change its direction by bending the body. Thus it continues alternately trying the two different reactions until it becomes free. This indicates that we have here an adaptive change in the character of the response without any change in the environment such as Jennings discovered in Stentor; for it is hardly probable that these different responses can be accounted for by changes in the pressure of the tangle owing to variation in the activity of the flagellum or to the bending of the body.

Reactions to Chemicals.—My object in studying the responses of Peranema to chemicals was to ascertain if possible whether or not the flagellum is sensitive. In these observations colored substances were introduced under the cover-glass either in solution by means of a fine capillary pipet or as crystals by means of a fine glass rod. The reactions of the animals were then studied as they swam toward the colored substance which gradually spread out in the process of diffusion.

The responses to chemical stimuli consisted in all cases observed of sharp bending of the body and an abrupt change in the direction of motion just as in the reaction to mechanical stimuli.

However, in the case of iodin-green crystals introduced dry the animals ordinarily reacted as soon as the tip touched the colored solution; while in the case of methyl-green introduced in the same way they usually did not react until the body was entirely or nearly surrounded by the colored diffusion from the crystals; and in the case of methyl-blue introduced dry or chromic acid or iodin in solution they responded before the tip of the flagellum reached the colored diffusion. In these reactions there was no indication whatever of orientation in the direction of the lines of diffusion as demanded by Loeb's tropism theory. The animals in all cases crawled about in all directions and came in contact with the solution at all angles. Our evidence, however, leaves us in the dark as to the sensitiveness of the flagellum, for the creatures responded in one case before the tip of the flagellum reached the colored portion of the solution, showing clearly that chemical diffusion so weak that the color is invisible may be still strong enough to stimulate the animals. Thus the possibility of direct action on the body itself of chemical solutions too dilute to be visible was not excluded in any case.

Reactions to Light.—Specimens of Peranema under the microscope were at different times suddenly exposed to light varying in intensity from zero to direct sunlight and then suddenly shaded again. In the case of the lower intensities there was no indication of any response, but in direct sunlight it appeared at times as though the flash of illumination induced the typical bending reaction, especially in specimens which had been kept in light of low intensity for some days preceding the experiments. But at best these responses were so indefinite that if there really are any to light they can be of very little significance under natural environmental conditions. There is no evidence whatever of orientation in horizontal rays of light such as is found in Euglena and other similar organisms.

The several different methods of response observed in Peranema may be described somewhat as follows: (1) Increase in rate of locomotion; (2) Change from crawling to swimming and *vice versa;* (3) The becoming active of a greater portion of the flagellum than ordinarily takes part in the activity; (4) Augmentation in the wave-like bodily contractions; (5) Local response to local stimulation; (6) Bending of the body toward the larger lip.

SUMMARY

1. Peranema usually moves in contact with the substratum by means of a combination of wave-like contractions of the body and the flagellum, but it can move by the action of either alone. The action of the flagellum is, however, ordinarily much more effective in locomotion than the wave-like contractions.

2. When very strongly stimulated, as by the addition of chemicals, it swims through the water free from the substratum much like Euglena. This is rarely seen under normal environmental conditions.

3. When crawling the flagellum projects straight forward; only the tip is active, and the organism usually moves on a straight course without rotation on the long axis. When swimming the entire flagellum beats in a rotary wave-like fashion, and the body rotates on its long axis and takes a spiral course.

4. Peranema does not orient. It responds to light very indefinitely if at all.

5. If the flagellum comes in contact with an object (tactile stimulation) the animal bends always toward the larger lip, then proceeds on a new course more or less nearly at right angles with the old. This same response can be induced by contact stimulation of any part of the body or by chemical stimulation.

6. There is sometimes local contraction at the point of stimulation but this does not appreciably influence the direction of motion.

7. If the body becomes lodged or entangled in debris while the animal is crawling, the tip of the flagellum gradually beats more and more vigorously and a larger part becomes active. If this does not free the animal it bends toward the larger lip so as to extend the flagellum in a different direction. This then beats again as before, after which the body may bend again. Thus the bending of the body and the activity alternate until the animal becomes free or fatigued. This behavior seems to indicate that we have here different methods of response to the same stimulus.

HUMAN REACTIONS IN A MAZE

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Seven figures

The purpose of this experiment is to compare the ability of human adults and children to learn a maze with that of white rats under approximately comparable conditions. We shall attempt to correlate the differences in the objective records with the differences between the three groups in intelligent ability with the hope that such a study will throw light upon the general problem of the interpretation of a learning curve in terms of intelligence.

The serious difficulty involved in the experiment is the attainment of conditions which may be regarded as in any degree comparable. The human maze was constructed out of doors in a small lot surrounded by a high board fence. This fence eliminated extraneous sources of disturbance and secured a privacy essential to good work. The plan of the maze is represented by Fig. 1. Its dimensions are 14 x 20 feet, with alleys of 2 feet in width. The true path is 78 feet in length, complicated by nine *cul de sacs*. The runways were constructed by stringing on posts strands of wire 2½ feet from the ground. The ground was leveled and covered with gravel so as to render the paths as homogeneous as possible. The subject is compelled to run the maze blindfolded and he is guided by contact of the arms or hips upon the wire strands constituting the sides of the runways. The construction of a maze of this size with high wooden sides was deemed impracticable. It is doubtful if the sides of the alleys of such a maze could be made as homogeneous to the human eye as they are to the rat. However, the desideratum in the experiment is the attainment of comparable subjective conditions rather than comparable objective conditions. Previous work has indicated that our mazes are so homogeneous that visual distinctions play an insignificant rôle in the rat's behavior. The rat learns the maze apparently in kinaesthetic and contact terms. Our purpose was to study the ability of humans to learn a maze under similar conditions. The elimination of vision was thus essential to the attainment of our purpose with any degree of probability. The possible disturbing factor is not the elimination of vision but rather the presence of a bandage.

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[1] With the exception of one group of rats, the experiments were conducted by Mrs. Hicks. The paper has been written by Prof. Carr, who is entirely responsible for the method of treatment and the hypotheses and conclusions advanced.

All four adult subjects and one of the children were familiar with maze experimentation and three of these were very familiar with the rat maze. It was thus necessary to construct the human maze on a plan entirely dissimilar to that of the Hampton Court maze, and yet to preserve a comparable set of difficulties. The Hampton maze presents seven blind alleys, while the human maze was constructed with nine. The individual *cul de sacs* of the rat maze are probably the more difficult. Any comparison of the relative difficulty and complexity of the two mazes is a matter of opinion, though in our estimation the rat maze is the more difficult.

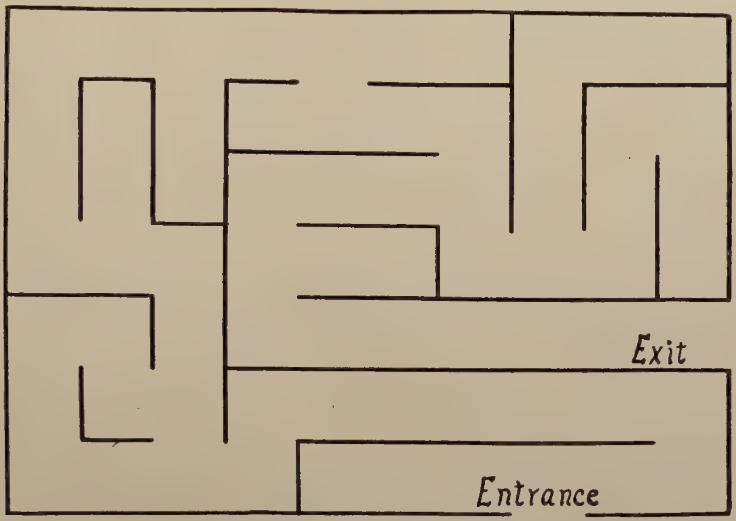

FIGURE 1. Ground plan of the maze used by the human subjects.

The matter of constructing mazes of comparable size presents difficulties. Shall the lengths of the pathways be proportionate to the body lengths, to the length of stride, or to the rate of movement? The results will vary according to the criterion used. The human maze presents a true path of 78 feet with 72 feet of blind alleys as opposed to 40 feet and 32 feet respectively for the Hampton maze. The human maze is thus approximately twice the size of the rat maze, a ratio which is too small according to the length of body or to the length of stride. The mazes are more nearly comparable from the standpoint of the rate of movement. Both human and animal subjects present marked individual differences as to rate of movement. The rats increase their rate of movement during successive trials more than do the humans. In the final trials an average speed of 64, 105, and 79 feet per minute was attained by the adults, children, and rats respectively. Our proportions thus fulfil the conditions of none of these three criteria exactly.

The human maze was constructed in an enclosed yard with a door which was kept locked. The subjects were kept blindfolded during the time they were inside of the yard. Their knowledge of the maze was thus confined to that derived from their experiences in traversing it. To those subjects who possessed no idea of a maze, only the necessary information was vouchsafed, *viz.*, that there was a winding path bounded by wires with only one outlet, and that they were expected to keep moving until this egress was found. They were instructed that success would be evidenced by finding themselves in the open untrammeled by wires, and that the experimenter would call to them if necessary when success was attained. No directions as to method of learning were given, each subject being allowed to learn the maze by his own natural method. Our purpose here was to avoid all constraint; freedom and ease are essential in order to maintain conditions comparable to those obtaining for the animals. The novelty and puzzle character of the task, and the knowledge that other subjects were learning the maze furnished sufficient motives for good records. Introspective analysis was neither demanded nor encouraged. The object was to eliminate as much as possible all memory and study of the maze between trials, so as to approximate conditions which may be legitimately ascribed to the rats. Introspection would tend to fix certain details more firmly in mind and encourage recall between trials. Some introspective knowledge was gained from the subjects' spontaneous remarks. The subjects were introspectively quizzed after the maze was learned. This mode of procedure eliminated the possibility of obtaining some very interesting and important knowledge of the learning process, but our interest was centered, however, upon the objective records obtained under comparable conditions.

We secured records from five children with ages ranging from 8 to 13 years. One of these was very familiar with the Hampton maze and with the rat experiments. The remaining ones were entirely ignorant of the experiment. Four adult males were used. These were all graduate students. Two of these had a practical knowledge of animal experimentation, while the knowledge of the other two was general in character. Records were taken for time, error, and the total distance traversed. A runway was regarded as the unit of error and returns over the true path as well as entrances into *cul de sacs* were regarded as errors.

Comparisons will be instituted between the records of the human subjects and the data derived from two sets of rats run on different mazes and by different experimenters: (1) A group of seventeen animals tested by Mrs. Hicks on the Hampton Court maze and (2) a group of six rats tested by Prof. Carr on a maze with a true path of 30 feet complicated by nine *cul de sacs* whose combined length is 14 feet. The second maze is hardly as complex as the Hampton, and it appears more comparable in complexity to that used by the human subjects. The groups of animals will be termed R I and R II.

I. THE NUMBER OF TRIALS NECESSARY TO LEARN THE MAZE

No correlation can be made between degrees of intelligence and the number of trials. The average and average variation for the adults and children are 11.25 ± 3.9 and 11 ± 2 respectively. The same values for R II are 12 ± 3.6. The individual records for the group R I on the Hampton maze were not preserved by Mrs. Hicks, so that comparisons in this respect are impossible. Miss Vincent, however, has kindly furnished the individual records of 10 animals on the Hampton maze which gave an average learning time of 11.4 ± 4.1 trials.

Mrs. Hicks's criterion of mastery for the human subjects was the ability to traverse the maze once without error, which is undoubtedly too low. The tests should have been carried further. Two successive trials without error were demanded

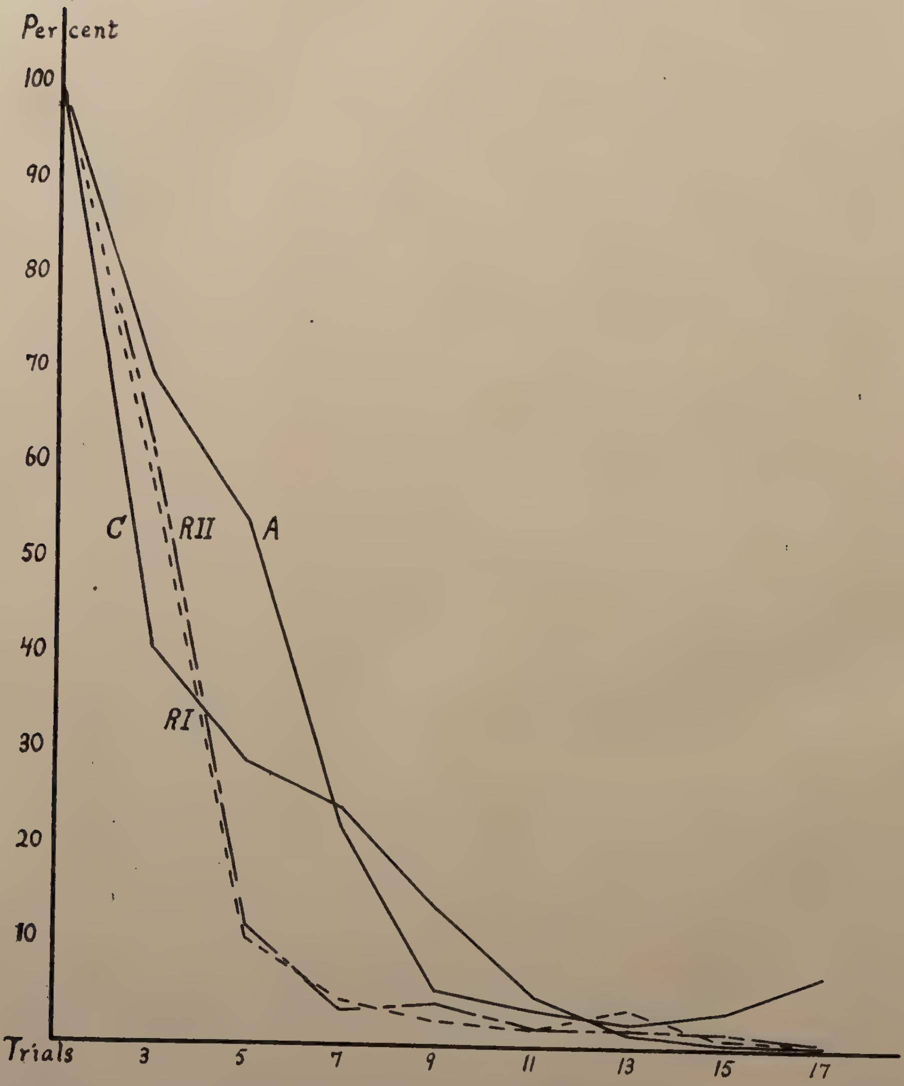

FIGURE 2. Curves representing in percentage terms the elimination of surplus time. A, curve for adults; C, curve for children; R I and R II, curves for the two groups of rats.

of both groups of rats. If but one successful trial had been demanded of the group R II, their results would be 7 ± 3. The values for Miss Vincent's group are 12 ± 4.6 when the criterion of mastery is the ability to run 8 trials out of 10 without error.

While the results indicate that the animals can learn a maze in a less number of trials than human subjects, yet one feels some hesitation in advancing such a conclusion in view of (1) the differences between the mazes, (2) the different criteria of mastery used, and (3) the small number of individuals constituting each group. One is certainly justified in concluding that no correlation exists between the number of trials necessary to learn a problem of this sort and the degrees of rational ability or of the general intelligence of the groups compared. This means that one cannot estimate correctly the relative intelligent ability of any two groups of organisms wholly in terms of the relative number of trials utilized in learning a maze. The conclusion does not mean that there is necessarily no causal relation between the two factors, but that if it does exist, it is obscured by more important factors.

II. GROSS VALUES ELIMINATED

A pronounced and unambiguous inverse relation obtains between the degrees of intelligence and the amount of surplus values eliminated. In a general way the ratios between the values eliminated are approximately 1:2:3 for the adults, children, and rats, respectively. Stated in terms of the usual curve of learning, these figures mean that the average height of the rat curve above the base line is three times as great as that of the adults, while the adult curve would possess but one-half the height of the children's curve.

Tables 1, 2, and 3 give the average surplus time, error, and distance values for the four groups for the successive trials. At the bottom of each column is given the average value eliminated per individual in the learning process, and the average individual amount for each trial. Referring to Table II, column I, it is seen that on the average each adult made 58 errors in learning the maze, or on the average 3.4 errors on each trial.

The surplus values for time and distance are computed by subtracting from the records of each trial the corresponding value for the last trial. If a rat traverses 90 feet in any trial,

TABLE I

Surplus Time Values in Minutes

Trial	Adult	Child	Rat I	Rat II
1	4.09	8.40	21.50	19.80
2	4.22	2.03	15.00	19.74
3	1.49	4.98	10.20	5.15
4	.76	2.10	3.50	3.42
5	3.70	2.77	1.20	1.43
6	1.16	3.04	1.50	.77
7	.67	1.04	.40	.57
8	.27	.98	.49	.35
9	.20	1.39	.61	1.23
10	.10	.64	.38	.21
11	.22	.27	.40	.52
12	.11	.06	1.26	.22
13	.07	.16	.29	.47
14	.15	.06	.18	.38
15	.15	.01	.22	.12
16	.16	.06	.11	.13
17	.45	.00	.05	.00
Total,	16.70	28.00	57.30	54.51
Average,	.98	1.65	3.37	3.20

TABLE II

Surplus Errors

Trial	Adult	Child	Rat I	Rat II
1	10.25	34.8	63.0	44.0
2	15.25	8.8	52.5	37.6
3	5.00	18.0	42.5	17.5
4	2.25	11.0	22.0	22.6
5	6.50	8.8	12.4	10.6
6	4.50	13.0	13.0	3.0
7	2.50	6.0	13.5	4.8
8	1.75	6.4	5.2	2.1
9	1.50	5.4	7.5	10.6
10	1.50	5.4	5.0	2.1
11	.50	.8	5.0	2.6
12	1.00	.4	10.0	.6
13	.75	.8	6.0	1.5
14	1.00	.4	6.0	2.6
15	1.00	.6	8.0	.6
16	1.50	.4	4.5	.6
17	1.00	.0	2.0	.2
Total,	58.0	120.0	278.0	163.6
Average,	3.4	7.1	16.3	9.6

and the length of the true path is but 40 feet, it is obvious that the animal has traversed a surplus distance of 50 feet. If the animal expends 2.50 minutes in any run, while the maze can be traversed after it is mastered in .30 minutes, a surplus of 2.20 minutes has obviously been expended in that trial. The values represent the surplus or unnecessary time or distance utilized in traversing the maze: they represent the effort or activity which is *eliminated* by the learning process, and not the effort or activity necessary to run the maze when learned. Obviously, all errors are unnecessary or surplus in this sense, and the error data of Table II are those commonly given.

There is but one exception to the inverse ratio. The distance values for the rats are less than those for the children, although much greater than those for the adults. This exception is readily explicable when the pronounced difference in the lengths of the two mazes is taken into consideration.

The ratios of 1:2:3 representing the values for the three groups were obtained by computing the ratio among the groups for the total time, error, and distance values separately and averaging the three values for each group.

The differences in the gross values are so great in proportion to the average variability (Table V) of each group, and their inverted relation to the general and rational ability of the three groups is so obvious, that one cannot refrain from concluding that some intimate causal relation exists between intelligent ability and the surplus values.

TABLE III

SURPLUS DISTANCE IN FEET

Trial	Adult	Child	Rat I
1	109.	540.	195.
2	138.	102.	165.
3	37.	99.	135.
4	8.	99.	65.
5	59.	105.	38.
6	37.	117.	45.
7	8.	99.	45.
8	30.	48.	22.
9	9.	60.	26.
10	6.	32.	14.
11	1.	10.	14.
12	1.	5.	20.
13	7.	5.	11.
14	7.	6.	10.
15	7.	2.	7.
16	8.	2.	5.
17	9.	0.	3.
Total,	480.	1351.	820.
Average,	28.2	79.5	48.3

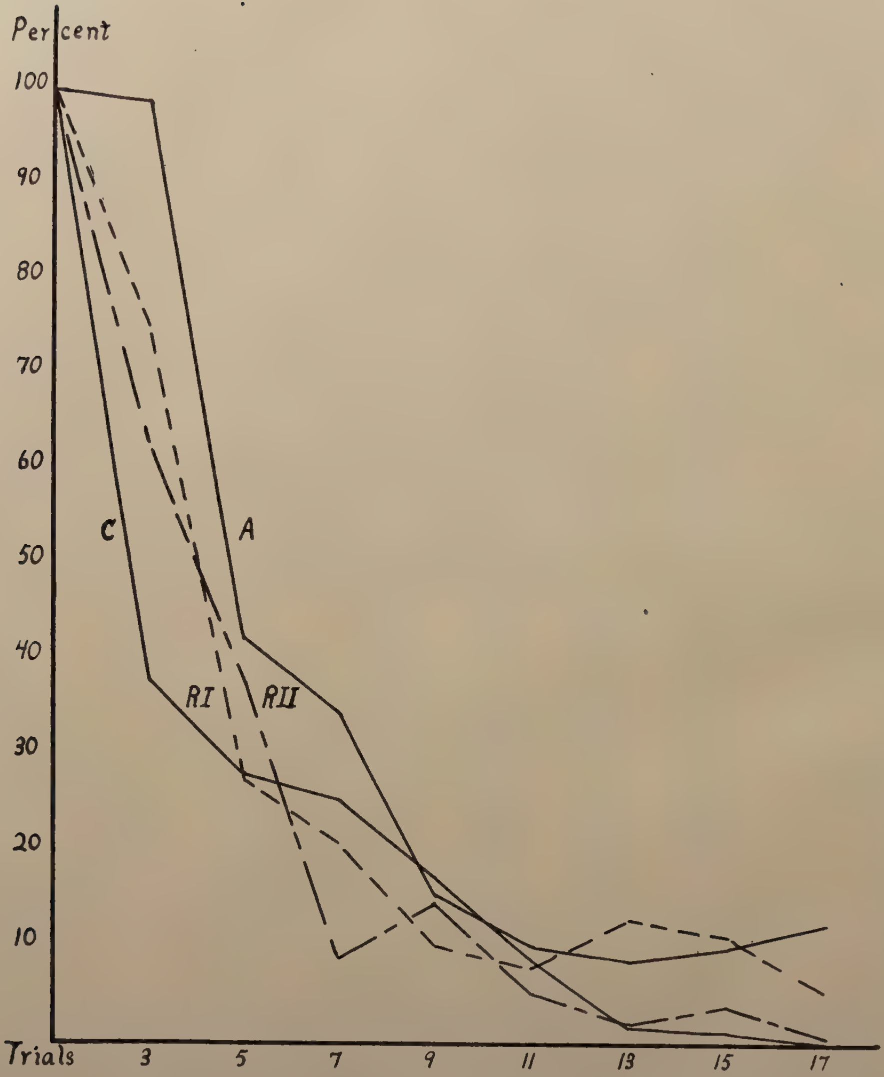

FIGURE 3. Error Curves; representing in percentage terms the rate of elimination. A, curve for adults; C, curve for children, and R I and R II, curves for rats.

III. RELATIVE RATE OF ELIMINATION DURING LEARNING PROCESS

The rapidity of elimination of the gross values is much greater during some parts of the learning process than during others. The extremely rapid initial descent of the curves representing animal learning is a well known phenomenon. The purport of this section is a comparison of the three groups in this respect. The comparison is facilitated by a translation of the gross values into percentage terms. By dividing the value of each trial by the value of the first trial, a series of percentage results is secured decreasing from 100 to zero. The value for any trial indicates the percentage of the initial value yet to be eliminated. These percentage values for the several groups are given in Table IV. The values for time, error, and distance for each trial are averaged, giving a set of results for each group of animals which represents a combination of the three criteria of time, error, and distance. Since all initial values are 100%, this method allows a superposition of curves, a device which renders comparison easy. In constructing the curves from these tables, we have averaged all results except for the first trial by twos, in order to eliminate extremes of variability. These curves are represented in Figures 2, 3, and 4. Several facts are obvious.

1. All curves exhibit the rapid initial descent. In a general way, 85% of the values are eliminated during the first half of the learning process. Obviously, this extremely rapid initial elimination cannot be interpreted as due to the functional efficiency of rational processes.

2. In the character of this initial elimination, certain differences obtain between the three groups for all the curves, and the rats represent a mean between the two extremes represented by the two human groups. The children make the most rapid initial elimination; the rate of the adults is the slowest, while both sets of rats occupy a mean position. But an inverse relation obtains between the rapidity of elimination and the number of trials over which it is sustained. The rate for the children is the most rapid, but it persists for the shortest time (3–4 trials). The rate for the adults is the slowest, but it persists for the longest time (up to the 9–10 trial). The initial spurt of the rats terminates around the 5–7 trials.

Since these differences are relatively pronounced, characterize all three sets of data, and apply to two sets of rats run by dif-

TABLE IV

Percentage Rate of Elimination

Trials	Adults				Children			
	Time	Errors	Dist.	Ave.	Time	Errors	Dist.	Ave.
1	100.	100.	100.	100.	100.	100.	100.	100.
2	103.	148.7	129.	126.9	24.	25.	19.	22.6
3	36.3	48.7	34.5	39.8	59.	51.	18.	42.6
4	18.5	21.9	7.5	15.9	25.	31.	18.	24.6
5	90.2	63.4	55.1	69.6	33.	25.	19.	25.6
6	28.3	43.9	34.5	35.9	36.	37.	21.6	31.5
7	16.3	24.3	7.5	16.0	12.4	14.	18.	14.8
8	6.6	17.	28.	17.2	11.6	18.	9.	12.8
9	4.8	14.6	8.4	9.2	16.5	15.4	11.	14.3
10	2.4	14.6	5.5	7.5	7.5	15.4	6.	9.6
11	5.3	4.8	.9	3.6	3.2	2.3	1.8	2.4
12	2.7	9.7	.9	4.4	.7	1.1	.9	.9
13	1.7	7.3	6.5	5.1	1.9	2.3	.9	1.7
14	3.6	9.7	6.5	6.6	.7	1.1	1.1	1.0
15	3.6	9.7	6.5	6.6	.1	1.4	.4	.6
16	3.9	14.6	7.5	8.6	.7	1.1	.4	.7
17	10.9	9.7	8.4	9.6	0.	0.	0.	0.

Trials	Rat I				Rat II		
	Time	Errors	Dist.	Ave.	Time	Errors	Ave.
1	100.	100.	100.	100.	100.	100.	100.
2	69.7	83.3	84.6	79.2	98.8	85.4	92.1
3	47.0	67.4	69.2	61.2	25.9	39.8	32.8
4	16.3	34.9	33.0	28.1	17.2	51.3	34.2
5	5.6	19.9	19.2	14.9	7.3	24.1	15.7
6	7.0	20.6	23.0	16.9	3.9	6.7	5.3
7	1.8	21.4	23.0	15.4	2.9	10.9	6.9
8	2.3	8.3	11.5	7.4	1.8	4.7	3.2
9	2.8	11.8	13.0	9.2	6.2	24.1	15.1
10	1.7	7.9	7.2	5.6	1.1	4.7	2.9
11	1.8	7.9	7.2	5.6	2.6	5.9	4.2
12	5.9	15.8	10.2	10.6	1.1	1.3	1.2
13	1.4	9.5	5.9	5.6	2.4	3.4	2.9
14	.9	9.5	4.8	5.1	1.9	5.9	3.9
15	1.0	12.7	3.9	5.9	.6	1.3	.9
16	.5	7.1	2.6	3.4	.7	1.3	1.0
17	.2	3.1	1.8	1.7	0.	.4	.2

ferent experimenters on two different mazes, one is forced to conclude that they represent genuine differences in the learning processes of the three groups. Moreover, since the rats stand midway between the two human groups, it is obvious that no correlation exists between the character of the initial elimina-

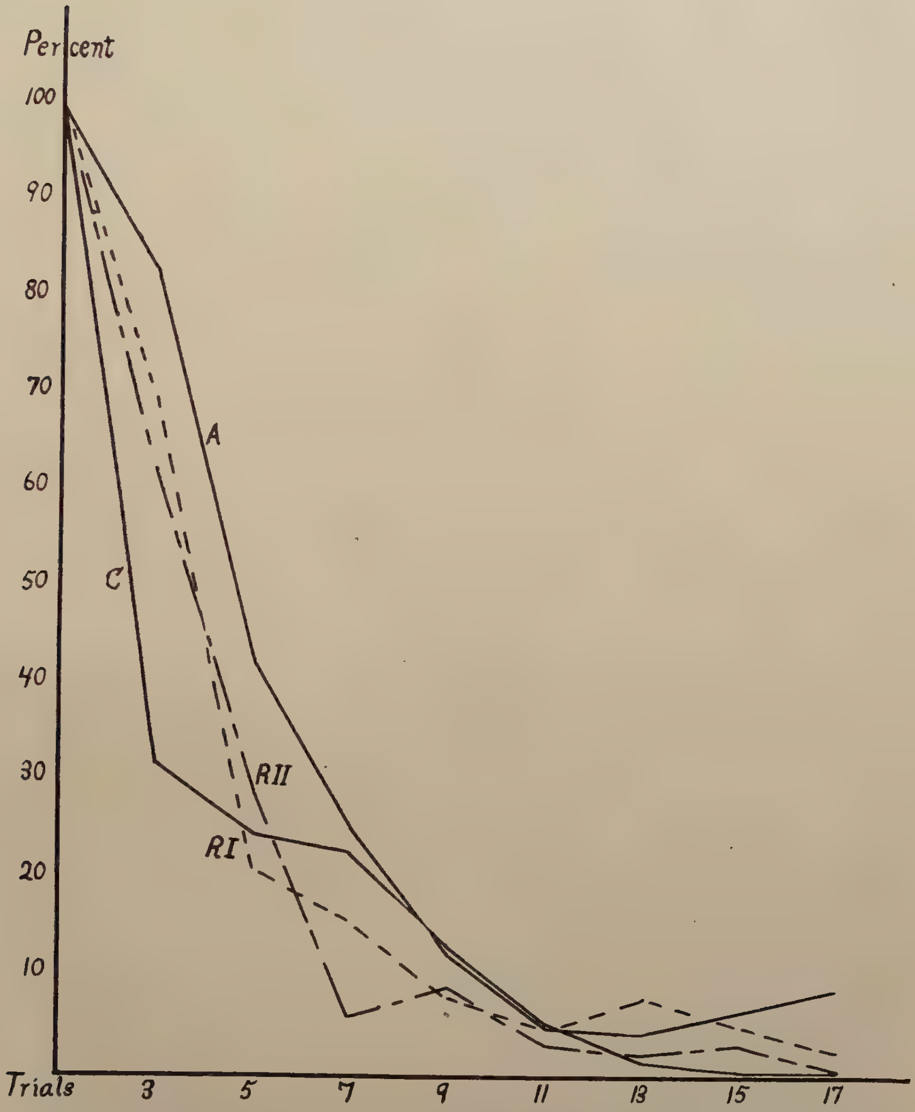

FIGURE 4. Combination Curves; representing the rate of elimination in percentage terms; obtained by averaging the data for error, and surplus time and distance. A, curve for adults; C, curve for children; R I and R II, curves for rats

tion and the rational ability of the organism. This does not necessarily mean that no causal relation obtains between rational ability and the initial progress in learning. If any causal relation obtains, it is indirect and obscured by other factors. One can merely conclude from these facts that one can not infer the relative intelligent ability of any two groups of organisms from this particular characteristic of their learning curves.

3. During the rapid initial spurt, the rate of elimination is not uniform. During some trials the elimination is more rapid than at other times. Certain differences between the groups exist in this respect. In every case the most rapid elimination occurs for the children during the 1–3 trials. For the adults this period occurs later in the learning process, between the 3–5 or 5–7 trials. The rats again occupy an intermediate position, though the curve is more similar in this respect to that of the adults than to that of the children. The most rapid elimination occurs generally from the 3–5 trials, though sometimes during the second and third trials. Again no correlation obtains between the phenomenon and the relative intelligence of the groups.

4. The children's curves invariably exhibit some indication of the plateau phenomenon from the third to the seventh trials. Some slight indication of plateaus are exhibited by the adults, but only for the error and distance values. The rats' curves give the least indication of this characteristic.

IV. COMPARISON OF TIME, ERROR AND DISTANCE ELIMINATION

The relative rate of elimination of time, error, and distance for any group might be shown by plotting the percentage values of Table IV. The facts can better be exhibited by the following plan. In comparing time and error, for example, the number of errors for each trial is divided by the number of minutes for the corresponding trial. This gives a series of values representing the number of errors made per unit of time for the successive trials. The ratios between these values are determined with the initial value regarded as unity, and these ratios are plotted in a curve. Any rise in this curve means that for that period the time values have been eliminated faster than those for error. A fall of the curve means that the errors have been decreased more rapidly than the time. The degree of difference in the elimination is represented by the height of the rise or fall. These curves for the various groups are given in Figures 5, 6 and 7. Each figure compares two sets of values, time and error, time and distance, and error and distance. In each couplet one factor has been regarded as the unit of comparison, and this is printed first in the heading. Time is the unit in two comparisons, and error is the unit in the third. This fact is important, from the standpoint of interpretation, because a rise in the curve means that the first or unit factor is decreased more rapidly than the second factor at that point in the learning process. With this key one can readily read the meaning of the curves in terms of relative rate of elimination.

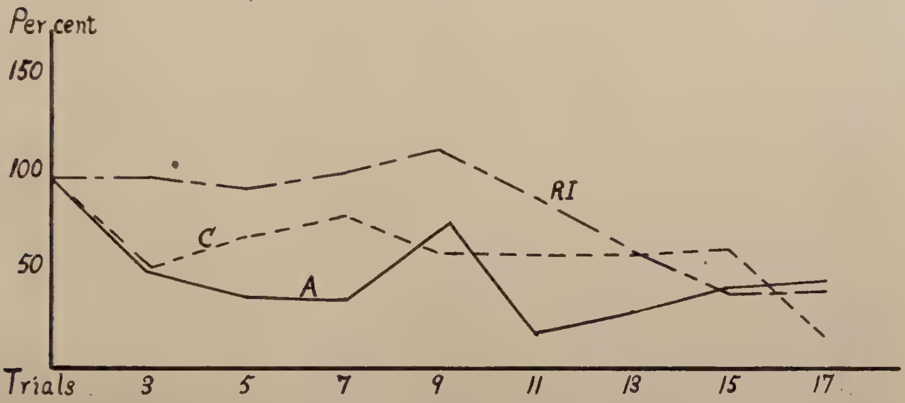

FIGURE 5. Error and Distance Comparison. Graphs representing the comparative rapidity of the elimination of error and distance values. A fall of the curve indicates that surplus distance has been eliminated faster than errors. A, adult curve; C, children's curve; R I, animal curve.

1. Error and Distance (Fig. 5). (a) For the entire learning process up to the 17th trial, all three groups eliminate distance more than errors and to about the same degree. The groups differ mainly as to the *period* in which this greater elimination occurs. (b) For the animals it occurs during the second half of the learning. The level line indicates that error and distance were eliminated at practically the same rate up to the ninth trial. The humans, on the other hand, perform this more rapid elimination of distance during the first part of the learning. (c) In a general way, the groups may be arranged in order in this respect similar to their order as to intelligent ability. The

curves of the adults and rats occupy the two extremes. The curve of the children is a mean, but it approximates more closely the adult curve than it does that of the animals.

The independent variability of error and distance can have but one meaning, when one considers the unit of error adopted in this experiment. Entrance into an alley constitutes an error, irrespective of the distance entered. At first the alleys are traversed throughout their entire length. In the later trials, the alley is only partially explored, this being sufficient to identify the runway as a mistake. One error is counted in each case, but the distance traversed is much smaller in the second

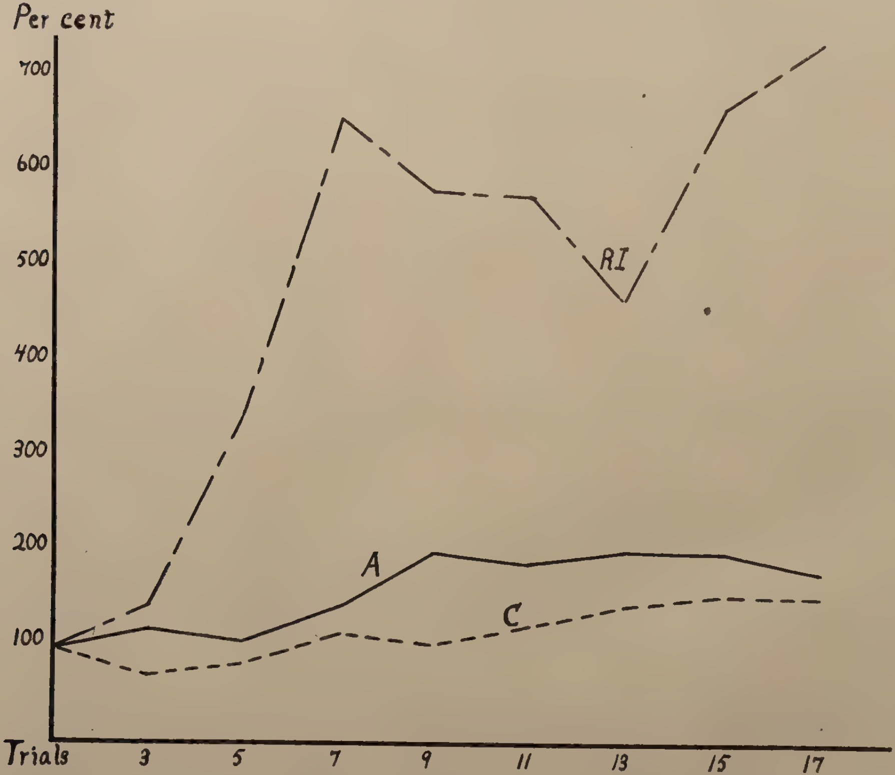

Figure 6. Time and Distance Comparison. Graphs representing the speed of running, or the rate at which distance is decreased in relation to time. Rise of curve indicates that time has been decreased faster than distance. A, adult curve; C, children's curve; R I, animal curve.

trial, i.e., the distance values have been decreased while the error values have not. The fact that all groups eliminate surplus distance values faster than errors thus indicates that at first they tend on the average to explore every runway throughout its length, while later they can identify a wrong runway by a partial entrance. This interpretation brings the comparative facts into some causal relation to intelligent ability, because the animals are not on the average able to perform this feat successfully until the latter part of the learning process, while the adults achieve the result mainly during the first few trials. Again, the adults are more successful than the children during this initial period.

2. Time and Distance (Fig. 6). In comparing time and distance, we are dealing with the factor of the speed of running for the various trials, i.e., the distance traveled per unit of time. (a) The average rates of speed of the adults, children, and animals, for the total learning process are 59, 79, and 52 feet per minute, respectively. The rats thus travel on the average almost as rapidly as do the adults. In fact they are much speedier in the final trials. (b) As to increase of speed, the human groups are approximately similar, while the rats stand in a distinctive class by themselves. They increase their speed seven fold. Some increase in speed is characteristic of all groups. The order of the three groups is not the same as that of their relative intelligence.

Obviously the facts are not explicable in terms of intelligence. The differences can better be explained in terms of peculiarities of the initial trials. The behavior of the rats is dominated at first by motives of caution and curiosity. A specific food motive is necessarily lacking. Slow, cautious, and random activity characterizes the first trials, and the speed of running is immediately increased with the introduction of the proper incentive. The incentive for rapid movements exists for the humans at the beginning. The children start out with a high degree of confidence and assurance, and run rapidly. In succeeding trials, they are forced by their blunders to run more slowly and cautiously (witness the initial drop of the curve), while the speed is again increased as mastery of the maze brings confidence and assurance. The adults proceed at the start with some dignity and circumspection and, as a consequence, their speed increases in a more regular manner. The initial values for the rats, adults, and children are, respectively, 10.5, 36.3, and 67.5 feet per minute. The final values in the same order are 79, 64, and 105 feet per minute.

3. Time and Error (Fig. 7). We find a pronounced distinction between the two groups of rats on the one hand and the human groups on the other. The animals eliminate time relatively faster than they do errors, while the human subjects eliminate errors more rapidly than time. The human curves are very uniform, while those of the animals are highly irregular. The period in which the greater elimination of errors mainly occurs for the human subjects is the second half of the learning process. The emphasis upon time by the animals occurs during the earlier trials. During the later trials, the animal curves fall in an irregular manner. That is, during the latter half of the learning, the animals eliminate errors faster than time and at about the same rate as do the human subjects. The main difference between the curves seems to be the matter of speed. The initial time values of the animals are exceedingly high,

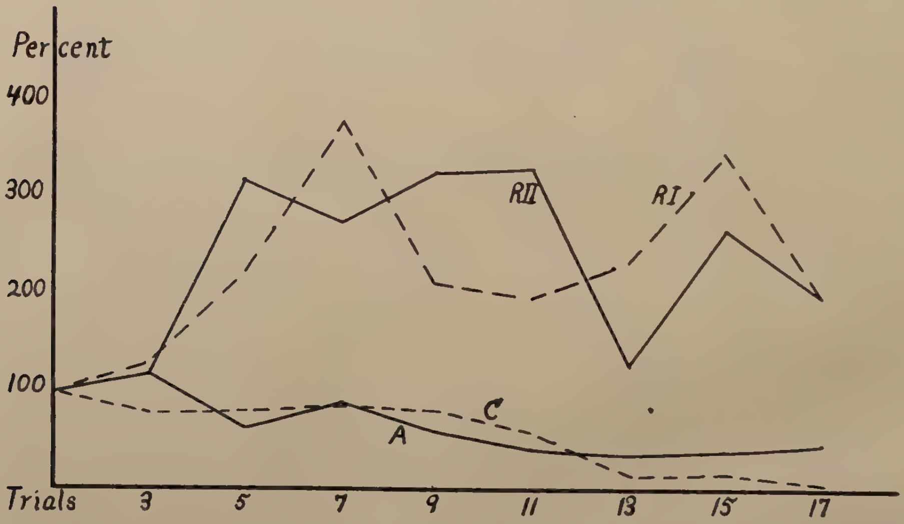

Figure 7. Time and Error Comparison. Graphs representing the elimination of errors in relation to that of time. Rise of curve indicates that time has been decreased faster than error. A, adult curve; C, children's curve; R I and R II, animal curves.

due to fear and caution and an absence of specific motive for a high rate of speed. After a few trials the time values are decreased, and from this point on the relation between time and error is more normal and similar to that exhibited by the human subjects.

V. RELATIVE VARIABILITY OF THE GROUPS

Comparisons in this respect were instituted in the following manner. The average and average variation values were computed for each group for such factors as the total number of errors, the surplus time, etc. Inasmuch as the rats made a much greater number of errors than the adults, the range of probable variation is also greater. Consequently, each average variation is divided by the average. This gives a percentage value expressing the ratio between the range of variation and the group average. These values have been termed the "percentage of variability," and they are given in Table V.

TABLE V

Percentage of Variability

	Adults	Children	Rat II
Initial Errors	15.6	19.8	57.5
Initial Surplus Time	34.6	32.4	41.8
Total Errors	26.7	20.7	29.0
Total Surplus Time	23.4	57.4	24.8
Number of Trials	34.7	18.2	30.0
Average	27.0	29.7	36.6

The average for each group is given at the bottom of the table and it is to be noted that the groups can be arranged in order of their intelligence. One might conclude, therefore, that the greater the intelligence the less is the variability between individuals. However, it must be recalled that four adults, five children, and six rats constituted the three groups. The probable range of variation inside a group depends, in a general way, upon the number of individuals composing it. Making allowances for this fact, no distinctive differences can be confidently affirmed, with the possible exception that the animals are more variable than the humans as to the initial values.

VI. RELATION OF THE LEARNING CURVES TO INTELLIGENCE

Our results indicate that the two features of any set of results which serve best as the main criterion or index of the intelligent capacity of a group of animals are the gross values eliminated during learning, and the rapidity with which errors are eliminated relative to surplus distance.

This conclusion is interesting because it runs diametrically opposite to current theory and practice. There have been in the main two assumptions as to the relation between a learning curve and the intelligent level of a group.

1. Both comparative and human psychology have tacitly assumed, at least so far as practice is concerned, that the rating of any two groups as to general intelligence is to be based solely and directly upon the number of trials involved in mastering a problem. This assumption is perhaps valid in memorizing nonsense material in such experiments as the Ebbinghaus type, in which the various trials are relatively homogeneous as to the amount of effort expended. In problems of a motor character (and this applies to all animal experiments and to much human work) the various trials are so radically disparate as to the time and effort expended that the assumption is without any rational basis. Moreover, the assumption is controverted by the facts of this paper. However, the inference must not be made that no causal relation obtains between general intelligence and the number of trials. We object to relying upon this feature as the sole or main criterion in rating general ability.

The position may be taken that the number of trials may be regarded as an accurate index of *special* ability—the ability to learn the maze problem. The writer is frankly skeptical of such an assumption although the point is irrelevant, for comparative psychology has not been using the criterion in this manner. It has been rating groups of animals as to their order in the intelligent scale, and this means general and not special ability.

2. Comparative psychology has also broached the proposition that the *rational* status of a group of animals can be legitimately inferred from such a feature as the " slope " of a learning curve. This assumption does not refer to general intelligent ability, but to *rational ability.*

Thorndike assumed that a *gradual slope* of a time curve is indicative of the absence of higher mental processes. The functional presence of rational processes would be evident in an abrupt descent. Hobhouse, while not explicitly accepting the assumption, called attention to the abrupt initial descent of Thorndike's curves and maintained that, according to the assumption, rational processes were functionally present. Watson questions the assumption and argues that this abrupt initial drop of learning curves can be legitimately explained in other terms.

The slope characteristic of any curve is determined by three factors which are to some extent independent variables. These are (a) the number of trials, (b) the surplus values, and (c) relative rate of elimination for different trials. Obviously, the slope of a curve increases as the number of trials decreases, when the other two factors remain constant. The abruptness of the slope is also directly proportionate to the size of the gross values, when the other factors remain constant. Likewise, two curves may be alike as to the gross values and the number of trials, and yet their slope may be radically different; one may exhibit a straight line descent, while the abrupt initial drop may characterize the other. Obviously, Hobhouse and Watson are discussing this " abrupt initial descent " as compared with the remaining portion of the curve, and this is the third factor mentioned, viz., the relative rate of elimination. Hobhouse assumes that Thorndike also referred to this feature of the curve. Thorndike's term " gradual slope " is to some extent ambiguous and the writer has often harbored the suspicion that the emphasis in Thorndike's mind was placed upon the " number of trials " rather than upon the " relative rate of elimination." Obviously a learning process which extends over twenty trials may be termed " more gradual " than one which terminates in four trials.

Our results indicate that any inference from such a general characteristic of a curve is not feasible, because we are dealing with a complex phenomenon due to several independently variable factors. Our results indicate that the rational status of a group of animals cannot be inferred from the slope of a curve in so far as this slope is dependent upon the number of trials or the relative rate of elimination. They indicate, moreover, that inferences as to intelligent status are legitimate in so far as the slope is determined by the factor of total values eliminated, but that the relation between the abruptness of slope and the degree of rational ability is just the inverse of that assumed by Thorndike and Hobhouse.

Several hypotheses may be advanced to explain the inverse relation between intelligent capacity and the gross values.

1. Differences in previous knowledge of the maze. Our experiment failed to establish comparable conditions for the three groups in the matter of previous knowledge of the problem. The humans knew the meaning of the problem; they knew that the maze was constituted of blind alleys and a true path with an exit. Their acts were purposively controlled by the motive of finding this exit as soon as possible. They were governed by no motives of curiosity or fear leading to idle and unnecessary exploration. The rats face a different situation. There is no distinction between blinds and true path. To them, there is no exit leading to food. The maze as an object from which to escape as quickly as possible constitutes a problem which the animals must discover by experience. Motives of fear and curiosity leading to random exploration are dominating factors which must be eliminated in the early trials. The motive of hunger at first stimulates but does not direct their exploring activities toward some exit. To the rats the maze at first is a strange, novel object to be explored and investigated in all its details, while to the human subjects it is primarily an object from which to escape as soon as possible. The rats proceed slowly and cautiously, while the humans travel with some speed and assurance. The human explorations are systematized, while those of the animals are random and discursive from the standpoint of reaching some definite position in the maze. One set of conditions tends to increase the initial values while the other set tends to minimize them.

Undoubtedly this conception is legitimate and the phenomenon is to be explained at least in part by such means. Two considerations may be urged against the conception as the *sole* principle of explanation. (a) The differences between the three groups as to previous knowledge of the problem is utterly disproportionate to the corresponding differences of surplus values. (b) If the differences in total values are to be explained entirely in such terms, then all three groups would make the same number of errors in learning the maze, provided they could start on equal terms. Making comparisons in terms of errors, group R I would be on terms of equality with the children and adults only after three and seven trials, respectively. If it were not for this handicap equivalent to a number of trials, the animals would learn the maze in a much fewer number of trials than the adults. The conception as the sole principle of explanation thus forces the further conclusion that the number of trials necessary to learn a maze is inversely proportional to general intelligence.

2. The second hypothesis concerns the functional efficiency of a *plan of action*. Let us suppose that a subject explores both sides of each runway carefully seeking for two diverging paths. He chooses one of these in a haphazard manner for exploration. The exploration is designed to determine whether or not this path is a blind alley. If by chance he choose the true path, he continues until he again comes to the parting of the ways. In case he chooses a blind alley, his mental effort is now devoted to the task of schematizing its spatial relations to the path over which he came and to the other diverging path. His purpose is to emerge from each alley that proves to be a blind and to continue on his way without any disturbance of orientation. Provided this result were attained in every case, the average number of initial errors for a group of subjects would approximate half the number of blind alleys in the maze. If the subject failed to maintain his orientation upon emerging from a blind alley, returns over the true path, and re-explorations of *cul de sacs* would result with a consequent increase in the time and error values. This ability to reinstate the previous sense of orientation upon emerging from a blind alley is no easy task. It involves during the exploration the construction of some representation of the spatial relation of the runway to other paths, and the mental ability to hold this scheme in mind until the previous orientation has been reinstated. The successful prosecution of such a plan of action does not necessarily result in the mastery of the maze during the first trial, because the subject is required to schematize and hold in mind but one segment at a time. The first segment learned may be forgotten long before the end of the maze is reached. The subject may also be unable to unite the various parts into a conceptual whole, and, granted the construction of a schematic

representation of the whole path traversed, it may not be remembered upon the second trial on the following day. This description of a possible plan of procedure is designed merely to illustrate our general proposition that any systematic plan of action must necessarily be effective upon the records of the trials, and that its effectiveness is proportionate to the character of the plan, to the mental ability of the subject, and to the persistency with which the plan is prosecuted.

This hypothesis is similar to the first in so far as the plan of action is derived from previous knowledge of the maze. However, we desire to emphasize several points. Two groups might be on a par so far as previous knowledge is concerned and differ immensely in the ability to use it effectively. One group might be unable to evolve an adequate plan, their judgment as to its adequacy might be poor, and they might be weak as to the virtues of persistency and pertinacity. Again, the development and choice of plans or modes of attack may depend not only upon the previous knowledge of the maze problem but upon experiences derived from widely disparate sorts of situations.

3. A third hypothesis assumes the efficacy of acquired habits and innate tendencies. Practically, the hypothesis is the same as that of purpose or plan, with the exception that the determining conditions are conceived as having no conscious correlate. Children are characterized by sensorial attention and curiosity. In popular terms they are all eyes and ears. Their nervous system is highly responsive to all sorts of objective stimuli; their reactions are determined mainly by objective conditions; relatively, they are creatures of the environment. Adults are more blase; they do not give themselves up to every chance novel stimulus; their reactions come to be more and more determined by acquired internal neural conditions; they are masters of, rather than slaves to, their environment. Psychology is accustomed to emphasize the positive phase of the selective character of habit in apperceptive reactions to sensory stimuli. Habit is also selective in a negative sense; it curbs or represses many of the original tendencies to response; it results in the neglect on the part of the organism of many seductive appeals to reaction. The general point to be emphasized is the fact that children are extremely sensitive to a wide range of stimuli, With accumulated experiences, adults become neglectful of

those stimuli which they have learned are probably of an inconsequential character. The wider the experience of an individual in the world, the more blase, as a rule, he is likely to be.

The same conception is applicable to animals. The behavior of the young is characterized by an almost feverish, irrepressible exuberance of activity of a highly random, impulsive, and purposeless character. Mature animals act, as a rule, with some degree of dignity, caution, and circumspection. They have rather thoroughly explored their environment and classified it in reactive terms. Their habits on the one hand have increased their sensitivity to certain stimulative features as objects of food and danger. On the other hand, habit has also curbed and repressed responses to the trivial and inconsequential aspects of the environment. As a result their energy is better directed and conserved for the more immediate and practical needs of the organism. The difference refers not only to the amount of activity, but also to its character.

This conception is applicable to differences between species, e.g., the comparison of the rats and the human subjects in our experiments, as well as to differences between adults and young of the same species. An organism with the greatest capacity for intelligence is, other things being equal, the most likely to acquire the greatest number of these inhibitory habits, and, as a consequence, is the least likely to give free rein to its discursive and random impulsive tendencies.

This view suggests the general proposition that the functional presence of higher mental processes inhibits and supplants the " motor excess " characteristic of the trial and error method of learning. Without the higher processes, the organism must rely for success upon the number of random movements; when conduct becomes guided more and more by higher processes, the extreme tendency to " motor excess " is not only useless but disturbing to the operation of the rational activities. This suggests that the degree to which organisms rely upon and utilize the trial and error method (excessive explorations) of learning may be determined by innate tendencies as well as by acquired habits and rational processes. An organism with little capacity for the higher sorts of intelligence, is necessarily constructed on the plan whereby this " motor excess " feature of behavior is accentuated. With organisms of higher mental capacity, this peculiarity of behavior is not necessary and, as a consequence, this tendency is repressed.

The relative validity and importance of these three explanatory concepts is immaterial to this paper. We are interested in maintaining the reasonableness of the assumption of a causal relation between intelligence and the surplus values. The proposition that the total values constitute the best single index of intelligent capacity is also rational from another point of view. The surplus values eliminated represent the amount of exploration, or the amount of motor effort, necessarily involved in the mastery of the problem. It is a customary assumption that the ability to master a task is inversely proportionate to the effort necessarily involved, and that the quantitative estimations of the amount of effort expended serve as the best criterion for judgments of comparative ability. In memory experiments of the Ebbinghaus type, the conditions are so arranged that the comparative amount of work expended by two subjects is best expressed by the "number of repetitions or trials." The same procedure would also apply to problems of the maze type, *provided* all trials were equal as to the effort involved. Obviously, the trials are utterly disparate in this respect and as a consequence the "total values" is the only aspect of the curves which represents in any adequate manner the factor of "effort." In this connection it is well to note that the "total values" also represent in a way the "number of trials," for, to a certain extent, the surplus values must vary with the number of trials.

The factor of "surplus values" cannot, however, be regarded as a very accurate or delicate index of intelligent ability. (a) While it is the only representative of the "amount of effort expended," yet it can not be considered as an adequate representative. The time and error values are directly proportionate to the *motor* effort, but their relations to any effort of an intellectual sort is more complex. The time values may be regarded as measuring the amount of mental work so far as its duration is concerned, but, as we have noted, the two are *inversely* related in respect to the *degree* or *efficiency* ofthe mental processes. (b) When the criterion is based upon the time and error values, the ratios between the three groups are

1:1.9:3.6. That these ratios express the relative ability of the three groups with accuracy is a doubtful proposition. The high degree of variability inside of each group must also be considered. The percentage of individual variability for time and error (Table V) is approximately 30%, for each group. It is doubtful if the intelligent capacity of the individual members of any group varies to any such extent. When corrections are made for the average variability, the above ratios should read 100 ± 30:190 ± 57:360 ± 108. Such values can express the relative status of the groups only in a gross and general way. (c) We have expressly refrained from maintaining that no causal relation obtains between intelligent ability and the "number of trials" and the "rate of elimination." If the "surplus values" represent the "amount of effort," the "number of trials" and the "rate of elimination" can be embraced under the caption of the "distribution of effort." Experiments on human memory have demonstrated that the "distribution of effort" is a very essential factor in economic learning. Preliminary experiments in this laboratory have also demonstrated its importance in such a problem as the maze. To maintain that such features should be totally ignored, in interpretations of intelligent ability, is preposterous. Furthermore, the three factors are not independent variables, but they are interrelated in a very complex manner. Intelligence is related to each factor both directly and indirectly. An insistence upon the intricate complexity of the three factors as to their relations to each other and to intelligence leads to several suggestions. (1) It helps to explain why the "surplus values" are not an accurate index of the degree of intelligence. (2) It suggests that an accurate index must be based upon some formula which shall give due weight to the element of "distribution of effort." (3) Comparative psychology has many problems to solve before making any attempt to rate the intelligent status of groups of animals on the basis of their learning curves. As yet practically nothing is known of the real meaning of a learning curve and the interrelations of its several features. (4) The conception renders explicable several peculiar features of our results. For example, there exists an inverse relation between the initial values and the number of trials. In so far as intelligence operates to cut down the values of each trial, it necessarily increases the number of trials. It is probably true that, other things being equal, the human can learn the maze in a fewer number of trials than the rats, but that this direct connection of intelligence with the number of trials is overpowered by their indirect relation through the factor of "total values." This inverse relation between the number of trials and total values is, of course, not absolute; no one maintains that the adults would have learned the maze in one trial provided they had bunched all their fifty-eight errors in the initial attempt. The inverse relation is not absolute *because* the element of "distribution" is an effective factor. In all probability the fact that the rats stand midway between the two human groups as to "rate of elimination" is explicable in some similar manner. The "initial drop" *may* be directly related to the rational processes as is assumed by Thorndike and Hobhouse. Yet, on the other hand, because the rational processes function to prevent any *cul de sac* from being repeatedly explored, they necessarily *prevent* the rapidity of this initial drop. As a consequence, this feature of the curves is related to intelligent ability in two antagonistic ways.

VII. CONCLUSIONS

For the maze problem, there are only two features of the numerical representatives of the learning process which can serve by themselves as direct indices of intelligent capacity. These are the surplus values of time and error, and the rapidity with which errors are eliminated in relation to distance.

These criteria are valid only for certain problems, and their accuracy and delicacy as indices are limited to relatively gross comparisons. Whether they serve best in estimations of rational status, general intelligent capacity, or of the special ability for motor acquisition is largely a matter of opinion.

Any accurate index of intelligent capacity must consist of some formula which shall give due weight to all factors: it must represent the "distribution" as well as the amount of effort. Such a formula must necessarily vary according to the problem.

The complex interrelations of the various features of any numerical representation of a learning process, the organic complexity implied in such a term as "intelligence," and the intricacy of the relations between "intelligence" and these numerical factors can not be too strongly emphasized in view of the tendency frequently manifested to rate animals in an intelligent scale on the basis of experiments in learning.

An experimental analysis of this complex situation constitutes a problem for any psychology which professes as an ultimate aim the ability to grade organisms in an intelligent scale from objective results quantitatively stated.

PHOTOTAXIS IN THE SEA URCHIN, *ARBACIA PUNCTULATA*

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GENERAL FEATURES OF THE REACTION

Arbacia punctulata, like many other species of sea urchins, is quite responsive to light and usually tends to go toward the darkest part of its environment, although more rarely certain individuals may show a pronounced positive phototaxis. This species may be quite fitful, however, in its reactions, and there is a very large amount of individual variability in the phototaxis of different specimens. When the sea urchins are brought near a window from a comparatively dark region they slowly wander away from the light approximately in the direction of the rays. When the dish in which they are contained is reversed they may again go away from the light, but after a few excursions of this kind they settle down and remain quiet. Even strong sunlight fails to disturb them for more than a short time. In fact, specimens remain phototactic in weak light longer than in light of high intensity, which quickly dulls their sensitivity. Specimens which no longer react to weak light may show a negative response of short duration when brought into strong light. Whatever the direction and strength of the light, provided all parts of their enclosure are illuminated to nearly the same intensity, the sea urchins do not remain for more than a limited period in the negative end, but become scattered in entire disregard of the direction from which light falls upon them.

After sea urchins have ceased to respond to the light they may be induced to resume their phototaxis by mechanical stimulation. Poking the spines about or picking up an individual and setting it down again usually starts the creature crawling toward the negative end of the dish. Stimulation by chemicals has the same effect. Since locomotor movements are somewhat unwonted activities under the natural conditions of the sea urchin's life and involve a condition of more or less general excitement, they tend to exhaust themselves rather quickly. The effect of disturbance upon the creature's phototaxis is apparently that of producing a condition of activity which is directed and controlled to a certain extent by the rays of light.

When sea urchins are brought near a source of light there is produced a general movement of the spines and tube feet over the whole surface of the body. The points of the spines move back and forth or describe a more or less circular course, each spine moving in a manner different from its neighbors. The tube feet are extended, retracted and bent in various directions. Soon order begins to emerge out of this chaos of actions. The spines on the side toward the light become depressed and relatively quiet. Those on the opposite side tend to become somewhat raised. The spines on the sides, and especially those that reach the bottom move back and forth, and tend, when they are pulled back, to force the animal ahead. The movement resembles that of a galley rowed by numerous oars. The spines can frequently be seen to be raised somewhat when they are carried forward as an oar is in rowing. There is considerable irregularity in their movements, but there seems to be a predominant tendency to combine a downward movement with the backward phase of the stroke, a circumstance which would easily explain the rôle of the spines in locomotion. As the sea urchin travels the test is raised and lowered at intervals owing to the irregular movements of the spines.

The movement away from the light is aided by the action of the tube feet. Those on the under side of the body are protruded and bent in the direction of locomotion. As they touch bottom they adhere by their terminal disk, contract, and thus pull the body forward. The direction of locomotion is not determined by a particular set of tube feet which lie on the anterior side, because all of these organs capable of reaching the bottom are brought into play. Anteriorly, posteriorly, and at the sides the tube feet as they extend are bent forward and co-operate to pull the animal along very much as they do in the locomotion of the starfish described by Jennings.

Generally also, there is an extreme extension of several of the tube feet from the equatorial or upper region of the corona on the side away from the light. Those on the more illuminated side are more retracted. The extended tube feet sway back and forth slowly like long feelers exploring the region in front of the body.

When light falls on Arbacia vertically and one-half of the test is shaded the animal crawls directly into the shade. If placed where sunlight falls upon it obliquely from above and if either the right or the left half of the body is shaded by a board as the sea urchin crawls away, it travels in the general direction of the rays but deviates to a considerable extent toward the shaded side. If the side toward the sun is shaded and the sunlight allowed to fall upon the other half, the sea urchin will generally go against the rays of the sun toward the shade. The sea urchin, as we might expect, tends to go away from whatever side is the more intensely stimulated.

Occasional individuals show a positive phototaxis under the same conditions in which others are strongly negative. One such individual made six successive straight trips toward the light after which it became indifferent or slightly negative; several others showed a positive reaction which was nearly as persistent. In the positive reactions the spines are bent slightly downward on the side toward the light and are raised on the opposite side; and several of the tube feet from near the equatorial region of the test become greatly extended in the direction of locomotion. In all of the positive specimens examined the rate of movement was slow compared with the negative ones and occurred only in rather dim light. It cannot be said, however, that the majority of specimens observed were positive even in very dim light, although strong light produced a negative reaction in all specimens in which a well marked phototaxis occurred.

Removal of the organs in the ocular plates which have falsely been regarded as eyes produced, contrary to the statement of Romanes[1] for Echinus, not the least change in the reaction to light.

REACTIONS TO SHADOWS

Arbacia reacts to shadows in much the same way as several other species of sea urchins. Pass a dark object over it and the spines are erected so as to stand out at right angles to the surface of the body. This reaction may be repeated three or four times, after which the animal fails to respond. After several minutes of rest the action may be again induced. Keeping individuals in the laboratory for some days diminishes their sensitiveness to shadows, and indeed their reactions to photic stimuli in general.

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[1] Jellyfish, Starfish and Sea Urchins, p. 321.

The reaction to shadows is doubtless of service as a protective device, as it has commonly been regarded. There seems, however, to be no manifest tendency for the spines to turn toward any particular region which is shaded. Small shadows were thrown upon various parts of the sea urchin. The nearest spines would react by becoming more nearly perpendicular to the surface. If the spine happens to point away from the shaded spot it is brought so as to point more nearly toward the object casting the shadow, but if it is pointing toward the shaded spot it reacts by straightening up as before. Horizontal light was thrown on several sea urchins and my hand was passed between them and the light. The spines pointed directly outward instead of toward my hand. To a sudden diminution of light the sea urchin responds by bristling up, regardless of the position of the source of the shadow.

Von Uexküll [2] found that spines on isolated parts of the test provided with a radial nerve would still show the shadow reflex, but that this reflex would no longer occur when the radial nerve was destroyed. I have repeated von Uexküll's experiments and obtained the same results.

LOCAL REACTIONS OF PARTICULAR PARTS

As we have seen, local shadows produce simply an erection of the neighboring spines. Local illumination, however, evokes a somewhat different reaction. Throw a spot of light upon the surface of a sea urchin and the neighboring spines will bend over toward the illuminated spot, regardless of their previous position. The nearest spines are the first affected, but the reaction soon spreads, if the stimulus is sufficiently strong, to the outlying spines, so that one may observe quite a cluster of spines pointing toward the stimulated region. The reaction is practically the same as that given to a mechanical or chemical stimulus. After bending toward the stimulated point for a while the spines subsequently sway about in other directions and finally come to rest. The effect of a beam of light thrown upon an extended tube foot is to cause it to contract in an irregular manner. The tube feet do not seem to show any particular response to shadows.

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[2] Zeit. f. Biol., 40, 447. 1900.

The reactions of the spines to light are independent of the central nervous system. Pieces of shell from the inner side of which all traces of the radial nerves were scraped away, were exposed to a concentrated beam which had traversed several inches of water. The spines would still bend toward the illuminated spot and could be made to bend over in any desired direction by throwing the beam on different points. The response of the spines to light depends upon the superficial nervous plexus as Von Uexküll found to be the case for their reactions to mechanical stimuli. How far these individual reactions of the parts help us to explain the behavior of the animal as a whole is a subject reserved for later discussion.

EFFECT OF REMOVING THE SPINES

In several individuals the spines were entirely removed from the lower hemisphere of the test, leaving only spines which were incapable of touching the bottom. The specimens were then placed in a dish of sea water and exposed to the light. Soon they began slowly crawling away from the light and all assembled at the negative end of the dish. When the ends of the dish were reversed the specimens crawled away from the light as before and continued to do so in several other trials. The rate of movement was considerably slower than that of normal individuals.

Removal of the spines and tube feet from one lateral half of the body produced circus movements in most cases which brought the animal slowly away from the light in an irregular course.

EFFECT OF REMOVING THE TUBE FEET

Several times individuals were observed walking on the tips of their spines with the test raised about a centimeter from the bottom. Careful observation with a large hand lens, both through the glass bottom of the dish and in other cases through the sides when the specimen was placed near one edge, showed that none of the tube feet reached the glass. To make it perfectly certain that none of the feet escaped observation amid the mass of spines all the tube feet which bore discs were cut off with a pair of fine scissors. The specimens thus operated on crawled away from the light repeatedly. Their rate of movement was somewhat slower than that of normal sea urchins, but their course away from the light was apparently as direct.

EFFECT OF CUTTING THE NERVE RING

Specimens in which the nerve ring is destroyed still show the local responses to the illumination of particular parts of the body. The spines bend toward the illuminated spot and bristle up when a shadow is thrown upon them. If orientation is effected by the direct action of light on the parts of the body on which it impinges it is quite within the bounds of possibility that a sea urchin with the nerve ring destroyed would still be able to orient itself and crawl away from the light. The spines and tube feet on the two sides would be stimulated equally, those on the end away from the light would receive the least stimulus, while those toward the light would be affected most. A sea urchin with its independently responding motor elements deprived of the control of a common co-ordinating nerve tract is to a certain extent comparable to a cœnobic organism, such as Pandorina or Volvox, whose individual cells respond to light in such a way as to cause a phototactic movement of the whole colony. When we reduce the sea urchin to a system of independently reacting parts it is a matter of interest to find what happens to its phototaxis.

Several dozen specimens were accordingly operated on, in some of which the nerve ring was cut in several places; in others the internal organs were mainly removed, leaving intact, however, the radial nerves. The specimens subjected to the more severe operation lived for several days and were able to move their spines and tube feet about freely. They were exposed at several different times to ordinary light, artificial light, and direct sunlight, but not a single individual showed the least trace of negative phototaxis. Even after several hours exposure they remained in very nearly the same position in which they were at first placed.

In the specimens in which the nerve ring was cut great care was taken to produce the least amount of injury compatible with certainly cutting the nerve ring. A fine, sharp, bent scalpel was inserted into the mouth somewhat farther than the level of the nerve ring and a small slit was made in five places. The specimens were placed in running water and showed little effect of the shock of the operation. Some were experimented with soon after the nerve ring was cut; others were allowed to remain quiet for several days before being disturbed. As a rule the individuals operated on were in good condition and even the organs nearest the cuts showed little change in the character of their responses to local stimulation. Local responses to light and shadows occurred in the same manner as in normal sea urchins, and the general responsiveness of the animals indicated that shock effects played a comparatively small part in causing any changes which may have occurred in their behavior.

Numerous experiments were tried with the specimens operated on in order to give them every possible opportunity of showing a phototactic response. Neither in dim light, nor in direct sunlight was there any well defined movement away from the stimulus. Most of the experiments were carried on by exposing one-half of the animal to direct sunlight while the other half was shaded, as sea urchins have been found to respond most readily to light under these conditions. Continued experimentation with numerous individuals, with repeated intervals of rest in the dark to increase their sensitivity failed to elicit any movement away from the light in any sea urchin in which I was sure that the nerve cord had been cut. The lack of locomotor response was apparently not due to any failure in the response of the organs stimulated. If a sea urchin has one-half of the shell exposed and the other half shaded, the spines on the stimulated areas move more actively, as if they were making ineffectual attempts to carry the animal into the shade. The tube feet on the equatorial and upper regions of the body are more retracted on the stimulated side, while they are frequently much extended on the shaded side. The whole animal squirms and twists about uneasily, but it seldom gets more than a few millimeters from its original position even after hours of exposure, and is then as likely to become shifted in one direction as in another. Such a sea urchin gives one the impression of trying to get away from the stimulus, while being held back by the misguided action of some rebellious tube foot which fails to loosen its hold, or the contrary movement of certain spines. On carefully observing such an animal from below with a hand lens one can detect more or less working at cross purposes among the tube feet and spines. While the majority of the tube feet are very frequently directed away from the light there are several which do not fall into line with the others and whose failure to co-operate effectually checks the locomotion of the animal.

The direction in which the sea urchin moves is not determined simply by which motor elements exert themselves most vigorously. Locomotion is a corporate activity in which the various appendages co-operate much as they do in such animals as centipedes or insects. Cutting the nerve ring destroys the nervous connections through which co-ordinations are effected. The result is that there is so much misdirected activity that the sea urchin gets nowhere in particular. It may be that other kinds of sea urchins may exhibit a certain amount of phototaxis through the direct action of the parts most strongly stimulated by light. From our observations on the light reactions of the species experimented with such a result would not be surprising. Specimens operated on when first exposed to light would perform all the preliminary movements of the spines and tube feet as if they were going to crawl away like normal sea urchins; but not one of them got further than making a beginning.

GENERAL CONSIDERATIONS

We have seen that in the sea urchin light sets up a series of co-ordinated and definitely directed movements in relation to the source of the stimulus. It also sets up definite reflexes of particular organs of the sea urchin's body. The question naturally arises: How far can the light reactions of the animal as a whole be regarded as the result of these reflexes? Light falling upon the sides of the body causes the spines of those regions to make movements toward the light. We may assume that it tends to cause the tips to be depressed during their backward stroke, so that each spine performs a sort of rowing action which tends to push the body ahead, and there is a certain amount of evidence for this in the fact that the spines on the side toward the light are the most depressed while those on the opposite side are somewhat elevated. The spines on the posterior side of the body may be supposed to have their backward movement emphasized, while those in front, being less affected by the light, will act less vigorously or be somewhat raised because the light stimulates most the region lying above them. Light also tends to cause the tube feet to become more retracted on the stimulated side while they are extended freely in the shade. These reactions make for the locomotion of the animal away from the light, but by themselves they are insufficient to accomplish this result.

This circumstance does not I think afford a serious difficulty in interpreting the phototaxis of the sea urchin as belonging to the reflex type of behavior. Stimuli affecting one side of the body are responded to by movements of organs on the opposite side. It is probable that the sea urchin crawls away from the side stimulated by a beam of light for the same reason that it escapes from mechanical irritation. I have found that sea urchins in a dark room kept as free as possible from other sources of light except a small spot of intense light focussed on one side by a lens would crawl away from the source of stimulus. The light was passed through several inches of water to filter out the heat rays, and was screened away so that it had little chance to affect directly the parts which were active in carrying the sea urchin away. Since the animal had just shown itself irresponsive to light considerably stronger than that which reached any other than the spot most stimulated, we are justified in regarding its negative reaction as essentially like its crawling away from a point scratched by a needle. In these reactions the tube feet let go their hold near the stimulated spot, and those over the lower surface bend away from the stimulated side, extend, attach and pull the animal away. Along with this there is a parallel co-operative movement of the spines.

In these reactions there is no *direct* response to a stimulus on one side of the body by a reaction of organs on the opposite side as in the crossed reflexes of higher animals. The first response is near the stimulated point. From here the movement spreads until all the locomotor organs of the animal are involved. The stimulus to the activity of the distant organs is not so much the primary stimulus received from the outside as the stimulus afforded by the activities of the intermediate organs, as in the chain reflexes of higher forms. This spreading of a certain consensus of action, if I may use the expression, is the means by which the sea urchin reacts as a whole to outer stimulation. It is beautifully shown in the righting movements of starfishes where there may be at first antagonistic efforts of various arms, which are sooner or later overcome by a series of co-operative activities which extends from one attached arm until all the others take part in the unified impulse to turn the body over. It is also shown in the capture of food and its transfer to the mouth. The performance of a certain act by any of the numerous organs of the body of a sea urchin or starfish seems to stimulate neighboring organs to a like activity. Upon this characteristic many of the co-ordinations to be observed in echinoderm behavior apparently rest.

The foregoing experiments were carried on at the Bureau of Fisheries at Woods Hole, Mass., and I wish to thank Dr. F. B. Sumner and Mr. Pope for many courtesies received during my brief stay at that place.

SUMMARY

Arbacia punctulata generally reacts negatively to light of a great range of intensity, although it is occasionally positive in weak light.

After it has ceased to respond it may be made to resume phototactic movements by mechanical disturbance.

Movements away from light are generally effected by the combined action of the spines and tube feet, although phototaxis may occur when either one of these sets of organs has been removed.

Arbacia will move against the rays of light to get into a shaded region.

Arbacia responds to shadows by an erection of the spines and not necessarily by a movement of the spines toward a shaded area. The response occurs only a few times, but is resumed after a short period of rest. The reaction is dependent upon the radial nerves.

Local stimulation by light causes the spines to move toward the stimulated part. This reaction occurs in isolated pieces of the test which have no part of a radial nerve.

Strong light thrown upon the tube feet causes them to be withdrawn.

Cutting the oral nerve ring does not interfere with the local reflexes of the spines or tube feet, but it prevents the sea urchin from crawling away from the light. While reactions to local stimulation by light are of a character to aid in the phototactic response they cannot alone effect the locomotion of the animal. Phototaxis, like movements away from mechanical stimulation, depends upon a co-ordinated activity of various organs of locomotion.

A NOTE ON THE BEHAVIOR OF THE WHITE RAT

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One figure

In the brief note which follows, I wish to place on record an observation made on some white rats relative to the question of learning a problem by being "put through." The behavior in question derives its chief interest from its relation to facts and theories of animal behavior as presented by Thorndike[1] and by Cole.[2] For this reason it will be well to summarize the results of those writers.[3]

Thorndike describes his tests as follows: "A cat has been made to go into a box through the door, which is then closed. She pulls a loop and comes out and gets fish. She is made to go in by the door again, and again lets herself out. After this has happened enough times, the cat will of her own accord go into the box after eating the fish."[4] If, however, the animal is dropped through a hole in the top of the box, the same number of trials will not suffice to induce it to turn, after feeding, and re-enter the box. "The only difference between the first cat and the second cat is that the first cat, in the course of the experience, has the impulse ~~to~~ crawl through that door, while the second has not the impulse to crawl through the door or to drop through that hole. So, though you put the second cat on the box beside the hole, she doesn't try to get into the box through it. The impulse is the *sine qua non* of the association."[4] Three cats were made to enter the box. All turned and went in of their own accord by the 37th trial. Three were dropped through the hole in the top of the box. One was given 50 trials; one, 60; and one, 75. All failed to go in of their own initiation.

Cole repeated Thorndike's experiments on four raccoons. Two series of experiments were given. In the first, (Thorndike did not give a series corresponding to this one), the animal was lifted by the skin of the neck and dropped inside through the *door* of the cage. Cole found that between the 22nd and the 57th trials all the raccoons turned and re-entered the box of their own accord. From these tests, Cole concludes that any raccoon will re-enter the box at least by the 100th trial. In the second series, the animals were dropped through a hole in the top of the box as in Thorndike's experiments. By the 22nd trial all the raccoons used in this latter test climbed upon the box, *via* a step arranged for that purpose, and dropped inside. All, however, had been trained in the first experiment, i.e., in that of re-entering through the door.

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[1] Thorndike, E. L. Animal Intelligence. 1898. *Psych. Rev. Mon. Supp.*, vol. 2.

[2] Cole, L. W. Concerning the Intelligence of Raccoons. 1907. *Jour. of Comp. Neur. and Psych.*, vol. 17.

[3] Other students of animal behavior have worked with this problem of "putting through," but they have not used the particular method here under consideration.

[4] Op. cit., p. 67.

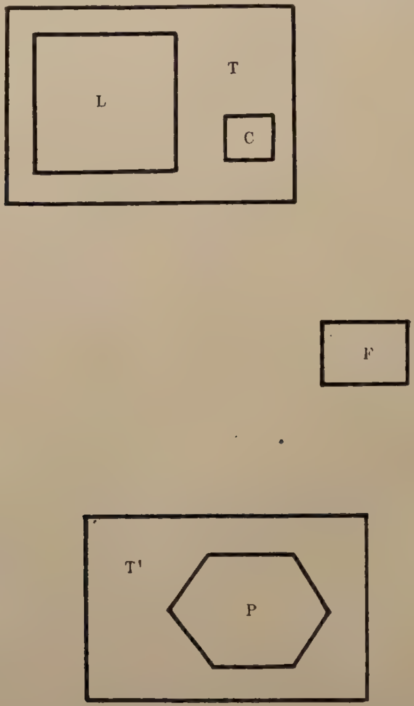

Figure 1. Plan of the arrangement of the boxes in the present tests.

Let us now turn to the observations on the white rat which it is the purpose of this paper to compare with the above results obtained with cats and raccoons. The rats in question were working on a problem in which the being "put through" was merely incidental. The apparatus was in the same room as the living cage, but on a separate table. Fig. 1 indicates the essential relations of the boxes to one another. *T* is the table upon which are placed the living cage, *L*, and a small accessory box, *C*. This latter is of wire and is 12 x 7 x 9 inches with an opening in the top 5 x 5 inches. *F* is a chair upon which food is placed during the day's experiments. *T′* is the table upon which the problem box, *P*, is placed. For 204 days, once each day, the rats were taken from *L* one by one and each given five trials in the problem box. The reward of each of the five trials was a bit of food given on the table *T′*. As the day's work with each rat was finished, the animal was picked up, by placing the hand about the body, and dropped into *C* through the hole in the top. When all the rats had been placed in *C*, a small quantity of food was put in the living cage, and the animals were picked up, lifted through the door of this cage and dropped within.

On the 204th day after the experiments were begun, the door of the living cage was accidentally left open, permitting the animals to come out upon the table. They ran about upon this, frequently pausing and sniffing the air in the direction of the food at *F* and of the experimenter who stood between the two tables. Within two or three minutes all the rats (five in number) had come to the box *C*. It was smelled of cursorily and passed by. But two of the rats climbed upon the box and dropped down inside through the hole in the top,—this despite the fact that they had never been fed in the box and that the rat odor alone could be there. This behavior they repeated on each of the next eight days and at frequent intervals thereafter until the close of the tests. The reason why the other rats did not eventually learn the reaction and why the two who had learned it tended to discontinue the reaction is undoubtedly to be found in the fact that the box *C* was not used in the experiments after the 204th day.

The complete method of handling the rats, when stated in terms of the symbols used in Fig. 1, is as follows: L-P-Food-C-L-Food. There are thus two complete cycles each culminating in the acquisition of food. When the rats were prevented from going through the first cycle, they initiated the second by climbing into *C*. This is not a case of abbreviated reaction similar to one noted by Cole.[5] There the raccoons shortened the path by which they climbed into the box: here the rats merely initiated the second complete cycle by necessarily eliminating the first one. In all essentials the behavior of the rats and the raccoons is in agreement. The reader may object, however, that the two sets of results differ fundamentally in that it is not known but what the rats would have behaved in the manner described even though they had not been "put through;" that, in other words, it was either chance or curiosity which led the rats into the box. In answer to this I submit the following: (1) The two rats that entered the box stayed in it until taken out. Had they been exploring merely, they would have left the box in a short time. (2) Chance is not the explanation, because the behavior was repeated for a little more than eight days. Again, (3) evidence against both chance and curiosity as the explaining factors is to be found in the fact that three rats failed to enter the box although the two others, as just stated, did so for some days. All five rats were close together on the table, so that this failure of three rats to follow the other two is very noteworthy in light of the results obtained by Berry.[6] This investigator records many instances where rats that had failed to leave a box, by doing which they would have secured food, did leave the box after they had seen (?) others give the reaction several times.

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[5] Op. cit., p. 239.

Let us now attempt a correlation of the three sets of data above given. Cole's results and those of the present writer oppose Thorndike's in the sense that both find that some animals (even those as low in the scale as the white rat), will learn certain problems by being put through them. Two possible reasons may be given to account for the fact that Thorndike's cats did not learn the reaction in question: First, they were not given enough trials. On *a priori* grounds, it is a valid assumption that it may take a much larger number of trials for an animal to learn a problem when being put through than when it experiences its own initiation of the act. Yet on the middle of page 67,[7] the inference is to be drawn that Thorndike thought *no* more trials should be required. Even twice the number of trials is not sufficient to justify the conclusion that an animal cannot learn by being put through.[8] A second and probably the fundamental reason why the cats did not learn the reaction is that dropping through a hole runs counter to native tendencies manifested in their behavior. Had Thorndike dropped the cats through the *door* as Cole did in one series of tests with his raccoons, it is not at all improbable that different results might have been obtained. One who has had occasion to observe the behavior of cats and raccoons can hardly have failed to notice their radical difference when it comes either to entering or to being put into a hole. Raccoons and rats, in their natural habitat, are accustomed to going in and out of holes in reaching and leaving their nests. In captivity they make no particular resistance when being put through a hole. Cats are just the reverse. They avoid dropping through holes, and it is all but impossible to put one through a hole. Thorndike has only recorded the vigorous resistance which his cats made to confinement. We are not told of their behavior when being put through the hole in the top of the box.

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[6] Berry, C. S. The Imitative Tendency of White Rats. 1906. *Jour. Comp. Neur. and Psychol.*, vol. 16.
See particularly experiments I and IV.

[7] Op. cit.

Thorndike used his results to prove that cats have no ideas to associate, only impulses. Cole, whose results are just the reverse, uses them in his conclusion that raccoons have mental images. If this interpretation be accepted as valid and Thorndike's experiments be regarded as conclusive, we are forced to take the position that rats, too, have mental images. Their mental life is thus on a higher plane than that of the cats. Few comparative psychologists, however, will consent to this relative classification of the animals.

If the various objections above noted be accepted, then the question of ideas is irrelevant to the cats' behavior in the present tests. It remains to be seen that this is also true for the behavior of the raccoons and rats. Reasons have just been given why instinctive tendencies may keep a cat out of the box, but it is doubtful whether instinctive tendencies will get raccoons and rats into boxes. The influence of instinct here is rather negative than positive. The effective factor is association. The constant use of the box as a link in the food getting series has made it attractive in itself, or, to state the matter differently, the very perception of the box has acquired motive power.

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[8] Op. cit., p. 66.

NOTES

THE DISCRIMINATION METHOD

The discrimination method, as described by me in the "Dancing Mouse"[1] and in greater detail in my report with Watson on "Methods of Studying Vision in Animals,"[2] demands, in the light of results which have thus far been obtained with it, certain criticisms. What I have to say at present in connection with the method is intended for the guidance of investigators who may wish to employ it in the study of sensory discrimination or other forms of organic reaction.

The method, as described in both references, consists, essentially, in the presentation to an animal of two objects which differ with respect to one or more characteristics on the basis of which the organism may select the one and reject the other. In one form, the method consists in the presentation of two visual areas of like size, form, and brightness whose discriminable difference is color. In another form, it consists in the presentation of visual areas which differ only in brightness, in size, or in form.

The conditions of discrimination, as thus presented to an animal, are somewhat unnatural, first, because the method is, as a rule, employed in a dark-room, and, second, because the objects to be discriminated differ in fewer respects than do objects which are usually dealt with in nature. Both of these possible objections to the method may be met satisfactorily by the experimenter, for the method may be employed advantageously under widely differing conditions of general illumination, and the objects to be discriminated may be varied in complexity as seems to the experimenter desirable.

In certain recent investigations with birds and mammals, the method has yielded negative results even after extremely long periods of training. I wish to point out that in some of these investigations the experimenters probably have wasted a considerable amount of time and energy by presenting to their animals visual objects which differ in only one respect: for example, in color, in brightness, in size, or in form.

It seems fairly certain that in our experiments we should not aim directly at our goal but, instead, begin with conditions which are rather more natural than those demanded for the accurate testing and measuring of any particular kind of visual discrimination by either the "brightness apparatus" or the "color apparatus." In an investigation of the perception of size, for example, it would seem safer to begin by using objects which differ in several respects. Thus the animal may more quickly be brought to attend to the proper objects and be trained to react appropriately.

Let us suppose that the initial condition of the experiment involved the use of objects which differed in brightness and form as well as in size. Then, just as soon as the appropriate form of response appeared, the experimenter would, by eliminating the three factors one after another, ascertain the following important facts: first, which of the three characteristics of the objects the animal naturally uses, as a basis for discrimination; second, the order of importance of the three factors for the purpose of discrimination; third, the ease, accuracy, and degree of delicacy of discrimination by means of each of the factors. Should the organism depend upon brightness at first, the experimenter might gradually diminish the brightness difference of the two objects until dependence upon it for discrimination became impossible. He might thus gradually bring the animal to attend to either the size or the form of the objects, or to both. Sbould it depend upon size, difference in form might immediately be eliminated and the experimenter would then be free to proceed with his special study of the characteristics of perception of size in the organism.

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[1] Yerkes, Robert M. The Dancing Mouse. New York: The Macmillan Company. 1907.

[2] Yerkes, Robert M. and Watson, John B. Methods of Studying Vision in Animals. *The Behavior Monographs.* 1911. vol. 1, no. 2.

In this experimental procedure there are, obviously enough, two important points: first, the use of conditions at the beginning of an investigation which are readily discriminated by the animal and which therefore permit of the acquisition of a habit quickly and without risk of discouragement; second, the directing of attention from the more readily perceived to the less readily perceived factors or characteristics of the objects through the gradual elimination of the more important factors; third, the simplification of conditions until, finally, discrimination is made to depend upon a single sensory factor.

By employing the discrimination method in some such fashion as has been suggested, the experimenter may not only obtain definite knowledge of the relative importance of different visual characteristics of objects, but he may also succeed in getting his animals to distinguish objects by means of a factor which otherwise could not be made use of. The secret of success is the gradual progress from the more important to the less important sensory factors of the situation. Several of us have made the grave mistake of demanding of our animals attention to objects which, although markedly unlike for us, were probably very much alike for them, or we have made the no less serious mistake of beginning with objects which differed in a number of important respects for the animals, and as soon as discrimination appeared we have eliminated factors and thus *abruptly* increased the difficultness of discrimination. Naturally, we have experienced difficulties in getting our animals to attend to the objects and also in preventing discouragement and refusal to attempt to discriminate.

There is further the important possibility of saving time and of obtaining positive results where they otherwise would not be likely to appear by the introduction of still other variations in the objects.

Professor Watson, in using the discrimination method for the study of color vision, has employed the device of a moving stimulus in contrast with a stationary stimulus. Thus, for example, a red stimulus area which is constant in position, size, shape, and brightness is presented beside a green stimulus area of like size, shape, and brightness, but appearing intermittently. At first, the intermittent stimulus may be interrupted at intervals of one second. This serves to attract the animal's attention to the visual areas. Gradually the rate of interruption of the one stimulus may be increased until flicker entirely disappears and the animal's attention may then continue to be directed to areas whose only difference is one of color.

A similar device has been used by Professor Casteel in his study of visual discrimination in turtles.[1] He placed white designs on pendulums and caused them to swing slowly back and forth in order that they might "attract and concentrate the attention of the animals."

Another important variation in the method is to present a single stimulus thus having only one object upon which attention is to be concentrated. The organism may be trained either to seek or to avoid the given object. Later, this object may be presented with a more or less similar object and discrimination on the basis of certain characteristics demanded.

Other variations may be introduced as seems desirable by the employment of stimuli for different senses. Visual and olfactory stimuli may be employed simultaneously, or olfactory and auditory, or visual, olfactory, and auditory. In certain cases, it may prove very advantageous to introduce stimuli which are naturally interesting to an organism even although those stimuli are not to be used otherwise than to control the attention and encourage the organism to effort.

Every experimental study of an organism emphasizes the importance of knowledge, insight, and ingenuity on the part of the investigator. He can not know too much about the habits, instincts, and environmental relations of the organism under consideration. Nor can he be too much given to distrusting and discounting the value of human experience as a guide in the study of animal behavior.

Finally, it may not be superfluous to emphasize the importance of avoiding the overworking of animal subjects, for especially in the higher organisms it is clear that too frequent necessity for reaction to a situation, even although the reaction can be made appropriately, has a bad effect upon the organism. It is extremely important, also, to avoid discouragement on the part of the animal. This may result from too frequent experimentation, too prolonged experimentation, or demands for discrimination under conditions which are overdifficult.

In connection with these dangers of experimentation, overfeeding is a frequent mistake on the part of experimenters. It is a good laboratory rule to supply animals with an abundance of sunlight, fresh air, to make them work for a living, and to restrict the amount of food obtained to that necessary to keep them strong and active.

ROBERT M. YERKES

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[1] Casteel, D. B. The discriminative ability of the painted turtle. *Journal of Animal Behavior*, 1911. vol. 1, p. 15.